# CONSTRUCTION WORKERS UNDER HARSH WEATHER CONDITIONS: MEASURING PHYSIOLOGICAL IMPACT

BY

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*Dreams are truly a treasure in each person's life. They represent our hope for a better tomorrow.*

*This dissertation is dedicated to my parents and my wife.*

*You have successfully made me the person who I am.*

*You will always in my heart*

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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| **PSM** | : | Physiological Status Monitoring |
| **PS** | : | Physiological Status |
| **HR** | : | Heart Rate |
| **BR** | : | Breathing Rate |
| $HR_{max}$ | : | Maximum Heart Rate |
| $VO_{2_{max}}$ | : | Maximum Oxygen Uptake |
| $METs$ | : | Metabolic Equivalents |
| **THR** | : | Target Heart Rate |
| **HRR** | : | Heart Rate Reserve |
| **BMI** | : | Body Mass Index |
| **%Fat** | : | Body Fat Percentage |

# ABSTRACT


Full Name : Ammar Saeed Mohammed Moohialdin

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One of the major sources of construction hazards in the Arabian Gulf is weather condition, where construction workers could suffer from high degrees of temperature and humidity. In such weather condition, temperature degree reaches in summer 45°C or higher and humidity 90% or higher. This research investigates the impacts of the harsh weather (hot and humid weather) conditions on construction workers' health and safety in one of the hottest region in the world (Al-Dhahran – Eastern province – Saudi Arabia), based on the physiological responses of construction workers. In order to provide a quantitative assessment for the Physiological Status (PS) of construction workers, real construction site measurements were conducted by using Zephyr™ technology, which is applied for the first time in construction industry in Saudi Arabia. The study considered weather conditions, type of activities (indoors/outdoors activities) and working shifts (morning/night shifts). In addition, considering fasting workers for the first time in such weather conditions. Based on the collected data, this research identifies the acceptable physiological zones and HR bounds as well as work intensity regions. Moreover, pilot study was conducted for testing utilized sensors and familiarize the researcher with its applications.

This research provides a practical implementation PSM technology in enhancing safety conditions of construction workers in Saudi Arabia and adds more knowledge regarding

this area of research. The results of the proposed research show that, it is highly recommended to adopt a real site monitoring system for construction workers' health and safety especially under such weather conditions in Saudi construction industry.

# ملخص الرسالة

**الاسم الكامل:** عمار سعيد محمد محي الدين

**عنوان الرسالة:** عمال البناء تحت ظروف الطقس القاسية: قياس الأثر الفسيولوجية

**التخصص:** هندسة وإدارة التشييد

**تاريخ الدرجة العلمية:**

تعتبر حالة الطقس من أهم مصادر المخاطر المهنية في قطاع الإنشاءات في منطقة الخليج العربي، حيث أن العاملين في هذا القطاع يعانون بشكل كبير من ارتفاع درجات الحرارة والرطوبة العالية. في مثل تلك الظروف القاسية للعمل قد تصل درجات الحرارة في أيام الصيف إلى 45 درجة مئوية أو أعلى والرطوبة إلى 90٪ أو أعلى. ومن هذا المنطلق فإن الدراسة المقدمة تهدف إلى دراسة تأثيرات ظروف الطقس القاسية (درجات الحرارة والرطوبة العالية) على صحة وسلامة عمال قطاع الإنشاءات في واحدة من أكثر مناطق العالم حرارة (الظهران - المنطقة الشرقية - المملكة العربية السعودية). وذلك إستناداً على القياسات الفسيولوجية للعاملين في قطاع الإنشاءات السعودي ضمن المنطقة المستهدفة مع مراعاة أخذ قياسات في أوقات الحر الشديد. من أجل تقديم تقييم كمي لتأثيرات درجات الحرارة والرطوبة العالية على عمال قطاع الإنشاءات، فإن الدراسة المقدمة عمدت إلى إجراء قياسات عملية في مواقع إنشاءات مختلفة باستخدام تكنولوجيا مراقبة الحالة الفيزيولوجية (PSM)، وذلك من خلال إستخدام واحدة من أهم أدوات القياس المستخدمة في هذا المجال Zephyr Technology و التي يتم تطبيقها لأول مرة في صناعة البناء والتشييد في المملكة العربية السعودية.
إن الدارسة المقدمة أخذت بعين الإعتبار الكثير من المتغيرات المرتبطة بتأثير درجات الحراة والرطوبة العالية على صحة وسلامة عمال قطاع الإنشاءات؛ حيث تم أخذ ظروف الطقس المحيط بعين الإعتبار إضافةً إلى نوع الأنشطة التي يقوم بها العمال (في الظل / في الهواء الطلق)، ونوع المهام التي يجب على العمال تنفيذها، واعتبار ورديات العمل المختلفة (الصباحية والمسائية)، إضافة إلى أخذ بعين الإعتبار ما إذا كان العامل صائماً ام لا بالنسبة للعمال المسلمين في رمضان. تعتبر هذه الدراسة الأولى على مستوى العالم التي تناقش مثل هذه الحالات التي تشمل عمال قطاع إنشاءات صائمين في رمضان. علاوة على ذلك فإن الدراسة المقدمة شملت إجراء دراسة تجريبية لاختبار الأجهزة المستخدمة من أجل التعرف على آلية عملها.
من خلال البيانات التي تم جمعها من اربعة مواقع عمل مختلفة خلال فترات الحر الشديد في المنطقة المستهدفة (الظهران - المنطقة الشرقية - المملكة العربية السعودية)؛ خلصت هذه الدراسة إلى تحديد الحدود الفسيولوجية المناسبة لعمال قطاع الإنشاءات لضمان سلامتهم تحت درجات الحرارة والرطوبة العالية وضمن بيئة العمل قيد الدراسة. كما يقدم هذا البحث تطبيقاً عملياً لأول مرة لتكنولوجيا PSM في تعزيز سلامة وصحة عمال قطاع البناء والتشييد في المملكة العربية السعودية، ويضيف المزيد من المعرفة حول هذا المجال. إضافة إلى ذلك فإن البحث المقدم ينصح بشدة على تبني نظام للمراقبة المستمرة في موقع العمل لصحة وسلامة عمال البناء والإنشاءات وخاصة في ظل هذه الظروف الجوية المرتبطة بصناعة البناء والتشييد في المملكة العربية السعودية.

# CHAPTER 1

# INTRODUCTION

This chapter addresses main concepts of construction workers' health and safety in general and then, an introduction about the impact of weather conditions on construction workers' health and safety. After that, this chapter will illustrate the application of innovative technologies for enhancing workers' health and safety especially Physiological Status Monitoring (PSM) technology. In addition, this chapter introduces the proposed problem and problem statement. After that, research aims and research approaches will be addressed in this chapter. Finally, this chapter will address the significant of the proposed research.

## 1.1 Background

Construction industry plays a major role in economic development in Saudi Arabia, where the Kingdom has achieved a real breakthrough in construction sector. The importance of construction industry in Saudi Arabia is reflected in governmental expenditure, which was increased by 49.6% during the period 1970 to1975, 32% during the period 1975 to 1980 and 49.8% during the period 1980 to 1985 (Jannadi & Bu-Khamsin, 2002). Saudi construction sector is also considered as one of the biggest markets in the Arabian Gulf, as well as in the Middle East. It is one of the most permissible sectors, where the growth records reached 20% at the end of 2013 (Saudi Arabia 2014|2015 Discovering Business, 2014). The development in Saudis construction sector is accompanied by a major development in construction workers' safety and health.

Workers' health and safety conditions in construction industry becomes one of the main concerns of construction companies and organizations, globally and locally i.e. in the world and Saudi Arabia. This concern is resulted from a hazardous working environment, which has a major impact on workers' safety, health, performance and productivity. Furthermore, construction workers are valuable resource having a significant impact on the success of construction industry, where construction employees constitute 7% of the total work force in the world. However, this percentage is associated with high number of accidents and injuries. The statistics reveal that 30 – 40 % of the fatalities are resulted from construction industry (Sunindijo & Zou, 2011). Moreover, construction industry workers in 2002 were considered the second highest category of the workers who are exposed to injuries in the United States, as more than 37% of the total injuries and illness are accounted for construction workers (Cheng, et al., 2013a). More recent studies also addressed high number of injuries in construction sector in the United States in 2011, where 15% of the total nonfatal injuries and 5% of the total fatal injuries were recorded in construction sector (Gatti, et al., 2014b). As it is illustrated in the historical records, there are a high number of injuries and accidents, which lead construction organizations toward investing more resources to identify the causes of hazards and so, eliminate and manage these causes. This concern also become a hot topic for researchers and academic institutes, as they try to employed innovative technologies in enhancing construction workers' health and safety in order to deal with the problem of increasing number of accidents and injuries.

Construction workers are performing heavy tasks (lifting, transportation, loading/unloading, hammering… etc.). Such activities demand physical exertion, in particular, under harsh weather conditions and difficult working environments (Migliaccio, et al., 2012; Cheng, et al., 2013a). For this reason, researchers argued that there is a relationship between working conditions (tasks type, working and weather conditions) and workers' behaviors, physiological status parameters (e.g. heart rate HR and breathing rate BR) and health/safety conditions (Lee & Migliaccio, 2014). Most of previous safety studies in the literature proposed survey or manual inspections based models for assessing the impact of harsh weather conditions, which depend on human judgment. There is a lack a quantifiable assessment for construction workers' safety level, which can be directly identified by assessing physiological status parameters (Gatti, et al., 2014b; Pradhananga, N., 2014). Although there are a number of studies that addressed construction safety in Saudi Arabia, there is a need for study on harsh weather conditions impacts (Alasamri, et al., 2012; and Al-Haadir & Panuwatwanich, 2011). Climate News Network addressed that there were frightening numbers of dead of Nepalese construction workers in Qatar in 2014 due to heat stroke illnesses (Trevor, 2014). Therefore, it is important for construction organizations and interested researchers to investigate the reasons of increasing number of fatalities caused by heat stroke and illnesses in Arabian Gulf region. Harsh weather conditions not only affect the impacts on the health and safety of construction workers, but also play a major role in their productivity levels.

One of major sources hazard in construction in Arabian Gulf countries is the weather condition. Construction workers are exposed to from high degrees of temperature and humidity. Temperature in the summer can reach 45°C even higher, with humidity of 90%

or higher (Joubert, et al., 2011). This weather conditions creates heat stress that significantly influence workers' health and productivity (Bates & Schneider, 2008). Construction workers who are performing demanding physical tasks under such weather conditions may suffer from physical strain and heat related illnesses such as "heat rash, heat cramps, heat syncope, heat exhaustion and heat stroke" in addition to lower levels of productivity (Liang, et al., 2011). This source of hazard is considered as one of the main obstacles for construction safety improvement in the Arabian Gulf. The Saudi government has issued some regulations that are related to working under harsh weather conditions as a preventive action to minimize the effects of extreme weather conditions on construction workers healthy and safety (Saudi Ministry of Labor Regulation (Working under a high degree of temperature prohibition), 2010).

## 1.2 Problem Statement

Construction industry is considered as one of the most hazardous industry in which workers are exposing to extremely hot and humid weather conditions especially in the hottest region such as the case in Saudi construction sectors. Extremely hot and humid weather conditions in Saudi Arabia has a major impact on workers' safety, health, performance and productivity.

This study addresses the problem of harsh weather conditions in Saudi Arabia and its impacts on construction workers' physiological status. This problem has not been addressed in Saudi Arabia. Another major problem is that, the construction organizations should focus on adopting more practical working thresholds for their workers and take this factor in account in tasks allocation and resting period planning.

## 1.3 Research Aim

This study aims to provide a quantitative assessment for the impact of harsh weather conditions (heat and humidity) on construction workers health and safety through conducting a real construction site data recording and observing for workers' physiological status by utilization PSM technology.

## 1.4 Research Approach

In order to achieve the stated research aim, this study started with a review of literature on different direction in construction safety studies. It was then followed by in-depth discussion and classification of previous studies in both impact of weather conditions in construction workers and application of PSM technology in construction industry as well as related fields. Following the literature review, a quantitative approach, as the selected research method, was performed by conducting observations at real construction site observation, and recorded construction workers' physiological status and weather conditions. The collected data was analyzed using statistical analysis in order to answer the proposed questions and to test the proposed hypothesis.

## 1.5 Significance of Research

The proposed study will add more knowledge regarding construction workers' safety and health in a very/extremely hot weather condition. The previous researches had been conducted in less harsh weather conditions such as US (Lee & Migliaccio, 2014), with maximum of temperature 65.3°F (18.5°C). The weather in Arabian Gulf Countries can reach temperature that greater than 135°F (45°C) with humidity level higher than 90%

(Joubert, et al., 2011). Moreover, there is limited study in the application of PSM technology in Arabian Gulf countries. The proposed study will address – for the first time – the application Physiological Status Monitoring (PSM) by using Zephyr$^{TM}$ Biohardness$^{TM}$ technology in Saudi Arabia.

The proposed study targets construction workers who are performing their normal tasks under harsh weather conditions construction sites in Al-Dhahran, Eastern province of the Kingdom of Saudi Arabia. In addition, it will help in identifying weather there is a significant different within different construction workers' behaviors and responses under same working and weather conditions, such as working in shifts (night and morning) and type of tasks (indoors and outdoors activities). it is important for construction organizations – in hottest regions in the world such as Saudi Arabia – to adopt a practical acceptable physiological zones and HR bounds based on the recorded data of HR and BR from real construction works.

## 1.6 Thesis Organization

This chapter addressed an introduction about the proposed study and a description about the problem statement. The following chapter will address the literature review and an in-depth discussion about what had been accomplished in the previous studies with considering construction workers' safety in general, weather conditions impacts and application of PSM technology for enhancing construction workers' health and safety. In addition, the literature review will include a subpart for special sensors used for PSM applications. The literature review studies will be addressed in detail discussion about the conducted researches addressing construction workers' health and safety in Arabian Gulf countries and Saudi Arabia as especial case. The last part of chapter two will address a summary about the literature review and the identified scientific gaps.

# CHAPTER 2

# LITERATURE REVIEW

This chapter focuses the literature toward two main concepts in this study, which are the application of Physiological Status Monitoring (PSM) for construction safety purposes with taking in account the most recommended tools and sensors in this field. In addition this chapter includes a literature about construction safety in Saudi's construction sector.

## 2.1 Introduction

Construction workers' health safety is a topic that has been addressed extensively in the literature' However, most of the previous studies addressed construction workers' health safety from the view point of managerial considerations, and risks/hazard management and analysis. This literature review chapter discusses a need for conducting more investigation in application of PSM technology in construction industry. It begins with addressing different directions of construction safety researches in Saudi Arabia and other Arabian Gulf countries. It is then followed by a discussion on application of PSM technology in construction industry, such as in assessing workers' health and safety; productivity and performance; heat stress; fatigue and work load; and ergonomic considerations. Finally, extensive literature on the application of Zephyr$^{TM}$ Biohardness$^{TM}$ in different fields is discussed, to demonstrate the applicability and reliability of this technology, as well as its advantages.

## 2.2 Construction Safety

Construction industry is considered as one of the oldest industry in human history, which is dated to the period 40 thousand and 12 thousand B.C. Started when the humans began to inhabit caves and prepare simple construction to be suitable for habitation. The first recorded steps toward managing construction safety were written in 2.2 thousand BC when the Babylon's king – “Hammurabi” - issued rules penalizing anyone who builds a building that collapses and kills its inhabitants (Zhou, et al., 2015). As a result of continuous development in construction industry whether in management systems, technologies, construction materials, equipment, methods and labor force, construction safety becomes a major interest of construction companies and governmental organizations in addition to the labor force. This is clearly illustrated in the literature review that is proposed by Zhou, et al. (2015), where the authors argued that there is a growth in research trend in construction safety based on the published papers (Figure 2.1).

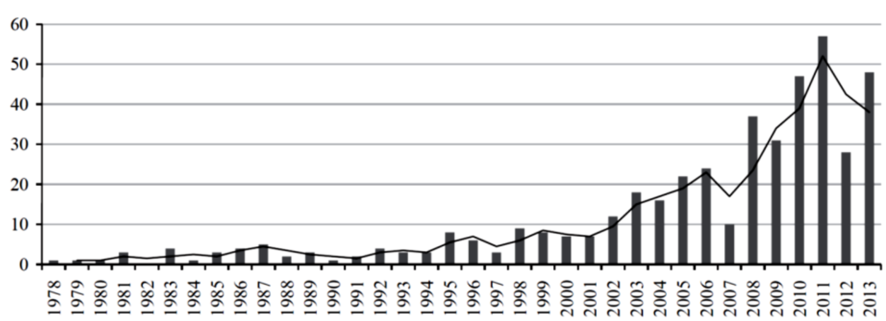


**Figure 2.1: Annual construction safety publications up to August 2013 (Zhou, et al., 2015).**

Figure 2.1 shows that in the first 13 years of the 21$^{st}$ century, there is a significant growth in annual publications on construction safety, which reached more than 50 papers in 2011. The authors proposed in their literature three categories of construction safety studies. The first category includes management, assessment and programs. The second category includes workers related considerations such as behaviors, perception and climate. The third category includes construction accidents and risks analysis. This classification could help both researchers and organization in identifying the effective tool for improving safety based on their interests. Furthermore, the authors concluded that, the more recent researches are directed toward the application of new technologies in construction safety. They identified some scientific gaps such as monitoring unsafe behaviors which is the main concern of this study.

The organization of the literature review in this section will follow the same classification as Zhou, et al. (2015). Different studies were conducted in order to examine different safety management systems and programs, while taking in account different perspectives and directions.

Implementation of construction safety programs plays a key role in reducing number of accidents and injuries in construction sites. Therefore, addressing the critical success factors, in addition to weakness of such safety programs, is an essential step toward improving safety. There is a large number of studies that addressed different factors and perspectives that is related to construction safety management. They include: management awareness and commitments (Choudhry, et al., 2007; Aksorn & Hadikusumo, 2008; Cheng, et al., 2012); training (Goldenhar, et al., 2001; Ismail, et al., 2012; Darvishi, et al., 2015; and Demirkesen & Arditi, 2015); working teams (Tam, et al., 2004; and Teo, et al., 2005); willingness to invest in safety resources (El-Mashaleh, et al., 2010); contractors selection criteria (Hallowell & Gambatese, 2009; Doloi, et al., 2011; and Alzahrani & Emsley, 2013); well prepared operations as well as governmental regulations (Tam, et al., 2004).

Moreover, “Occupational Health and Safety Assessment Series (OHSAS)” and “ISO Safety Management Systems” have issued well known safety standards such as OHSAS 18001:1999, ISO 14001 and ISO 45001. These safety management series were addressed in several construction safety studies in order to come up with an integrated safety management system that can be applied effectively in construction industry. To illustrate, Zeng, et al. (2008) addressed an assessment for the application of OSHA/OSHAS 18001 management system in construction sector in China. Based on the conducted questionnaire/interviews, the authors concluded that it is recommended to adopt an integrated management system (OSHAS 18001 and ISO 9001) that interrelates safety management system OSHAS 1800 and quality management system ISO 9001, in order to achieve the optimal utilization of the invested safety resources. Zeng, et al. (2010) also recommended similar integrated approach (OSHAS 18001, ISO 14001 and ISO 9001). They argued that such approaches provide an integration with the adopted strategies.

Several studies address safety management programs in construction sector in the Arabian Gulf Countries. Kartam, et al. (2000), for example, addressed the roles played by owners, designers, contractors and insurance companies in the implementation of Kuwait's safety regulations in construction sectors. The authors conducted their study by collecting data through sites visits, questionnaires and face-to-face interviews. They argued that despite of the awareness of governmental organization, owners and contractors about construction safety, they fail to translate the adopted goals to practical procedures having an effective impact on the resulted safety. Some factors that create this problem, which are disorganized labor, accidents/injuries recording system, large numbers of subcontracting, insufficient safety regulations, giving less priority to the safety, size of majority of construction companies, competitiveness during tendering stage, and extreme weather conditions.

The second direction of construction safety and health studies is related to safety climate and culture and its impacts on construction industry environment as well as on enhancing workers' safety (Fang, et al., 2006; Choudhry, et al., 2007; Aksorn & Hadikusumo, 2008; Choudhry, et al., 2009; Teo & Feng, 2009; Lingard, et al., 2010; Feng, et al., 2014). Some studies that addressed the relationship between safety level with workers' behaviors and attitudes toward safety consideration in construction industry (Zhou, et al., 2011; Chi, et al., 2013). A more recent study is in measuring construction safety climate by applying standard indicators called "core dimension structure of safety climate". These core dimensions include four main indicators, i.e. safety priority; safety supervision, training, and communication; safety rules and procedures; and safety involvement. This standard represents a practical guidance for measuring construction safety climate and culture, which provides an effective tool for predicting safety levels in construction organizations (Teo & Fang, 2006; and Wu, et al., 2015).

The third category of study includes construction accidents and risks analysis. There were several studies addressed the related concepts. According to Sousa, et al. (2014), construction accidents and risks studies can be categorized into three main areas, which include accidents analysis and preventions (e.g. Suraji, et al., 2001; Shapira & Lyachin, 2009; Cheng, et al., 2010; Cheng, et al., 2013) and risks analysis (e.g. Fung, et al., 2010; Pinto, et al., 2011; Badri, et al., 2012; Aminbakhsh, et al., 2013). Accidents and risk analysis are taking a large portion of construction safety studies. Different models were addressed with taking different perspectives, such as causation models (Abdelhamid

& Everett, 2000; and Mitropoulos, et al., 2005); and assessing and interpreting accidents' prevention (Wu, et al., 2010; and Kim, et al., 2010)

In summary, based on the factors that affect safety performance of construction industry, construction safety researches in the period of 2000 to 2015 can be categorized — into: Construction workers; construction management and organization factors; equipment, tools, materials and methods; workplace; weather conditions; workplace regulations and standards, application of new technologies; safety climate and culture; and accidents and risks analysis. 42 published researches were addressed in this section of the literature review. All of them addressed construction safety from managerial viewpoints. It can be concluded that the researchers tend to conduct studies addressing construction workers' safety and health from the management perspectives. This may be caused by the difficulties that are accompanied with conducting practical studies, which provides quantitative assessment of workers' safety and health in the real construction sites. These difficulties could be resulted from unavailability of related information about the innovative technologies well as benefits and related costs (Zhou, et al., 2013).

## 2.3 Heat and Humidity Impact

Most of the safety studies that are related to construction industry considered this industry as one of the most hazardous working environment for workers. This is due to the nature of the construction industry, which includes harsh and hazardous work conditions. Construction workers are more likely exposed to harsh and extreme weather conditions, such as; biological risks, chemical materials; unsafe ergonomics conditions; noise; vibrations; dealing with bulky and manual equipment/machines; electrical risks; dynamic nature of work; working in very high, confide and underground locations; and changeable tasks, working teams and working conditions are changeable from project to another or in the within the same project (Rozenfeld, et al., 2010; Sousa, et al., 2014). In addition, construction tasks include physically demanding activities, which have major impacts on construction health and safety (Boschman, et al., 2013).

Construction works includes physically demanding outdoor or indoor activities under direct sunlight. construction workers, while performing their tasks in construction sites, are exposed to harsh weather conditions (high degree of temperature and humidity) and hazardous working environments, which may lead to heat stroke symptom and heat illnesses, and even fatality. To illustrate, US Bureau of Labor Statistics (BLS) stated, there were 31 fatalities from construction workers due to high degrees of temperature in 2013 (US Bureau of Labor Statistics (BLS): Workplace Injuries). In Hong Kong, there were 43 injuries resulted from hot weather, which include 11 deaths in construction sectors during the period 2007 to 2011 (Li, et al., 2015). Koehn & Brown (1985) addressed four different injuries (Sunburn, Cramps, Heat Exhaustion and Heat Stroke) that may be resulted from working in hot weather. They denoted to that, breathing and body temperature is increased rapidly as a result of heat exhaustion and heat stroke respectively. Furthermore, OSHA standards (see Table 2.1) addressed that, it is necessary to measure the temperature in working place whether it is inside or outside doors. In addition, OSHA standards addressed "Wet Bulb Globe Temperature Index (WBGTI)" as an important index for measuring the impact of hot and humid weather conditions. However, Bates & Schneider (2008) argued that WBGTI is "too conservative and inappropriate" to be used in construction industry, especially in the very/extremely hot regions in the world.

**Table 2.1: Allowable heat exposure and work load limits (OSHA standards).**

| Work/rest regimen | Work Load | | |
|---|---|---|---|
| | Light | Moderate | Heavy |
| Continuous work | 30.0°C (86°F) | 26.7°C (80°F) | 25.0°C (77°F) |
| 75% Work, 25% rest, each hour | 30.6°C (87°F) | 28.0°C (82°F) | 25.9°C (78°F) |
| 50% Work, 50% rest, each hour | 31.4°C (89°F) | 29.4°C (85°F) | 27.9°C (82°F) |
| 25% Work, 75% rest, each hour | 32.2°C (90°F) | 31.1°C (88°F) | 30.0°C (86°F) |

Table 2.1 illustrates that, the suggested OSHA standards address method for working and resting period planning with taking in account working load (light, moderate and heavy). However, different people have different responses and behaviors based on their nationality, physical body conditions, health conditions and type of activities, which make these standards are not suitable to be applied in very/extremely hot regions such as Saudi Arabia (Bates & Schneider, 2008).

Harsh weather conditions, including high degrees of temperature and humidity levels, have a significant impact on construction workers' health and safety conditions as well as their productivity levels. In this context, there are several studies addressed the impact of high degrees of temperature on construction workers. To illustrate, Kjellstrom, et al. (2009) investigated the impacts of hot weather on human body by applying "Wet Bulb Globe Temperature (WBGT)" index, which is more commonly used as an indicator for weather conditions severity in different industries. The authors aimed to identify the appropriate heat exposure and work intensity by maintaining workers' core temperature below 38°C. In addition, the authors argued that workers in extremely hot regions in the world are exposed to heat stress and illness therefore, continuous monitoring of their conditions is a priority in order to achieve safer working environment. Furthermore, high degrees of temperature will cause a heat stress and consequent related illness, and resulted fatigue, which lead to physical fatigue and may reach to mental effects. Degree of severity of the hot weather impact is influenced by several factors, e.g. degree of temperature, humidity, radiant heat, wind speed, physical activities, and clothing worn by workers (Rowlinson, et al., 2014). Rowlinson, et al. (2014) argued that, the effects of hot weather could be reduced by adopting threshold system, managing working and resting periods, allowing working to self-pace. Furthermore, a new approach for addressing the impact of weather conditions on health and safety conditions of construction industry workers was addressed by Lee and Migliaccio (2014). The authors were able to investigate the impact of hot and cold weather in the USA by identifying the acceptable heart rate bounds and zones. Further investigation in hot and humid weather impacts was conducted by Yi & Chan (2015). These the authors were able to identify the optimal working and resting hours in order to minimize health hazards that are resulted from hot and humid weather conditions. In addition, the authors addressed that it is necessary to adopt safety guidelines for managing working hours in construction industry under hot and humid weather condition to avoid heat stress and illnesses. Even though large number of researches has addressed construction workers' health and safety, there is a need for more investigation, especially in very/extremely hot regions in the world or during the hottest sessions in the year, because construction workers are suffering from heat stress and illnesses mostly during this period (Alshebani & Wedawatta, 2014).

Arabian Gulf weather conditions are one of the hottest weather in the world (Joubert, et al., 2011). Harsh weather conditions are considered as one of the most influential factors having a significant impact on construction workers' safety and health in Kuwait (Kartam, et al., 2000). McDonald, et al. (2008) argued that, there is a high need to adopt a real-time monitoring system to monitor workers' health condition under extreme weather conditions. The authors examined the impact of hot and humid weather in Qatar in order to assess working conditions in such very hot region. In addition, the authors addressed one of the most applicable standards for heat stress, which has been adopted by Saudi Aramco (SA) as a reference for heat stress. The proposed index correlates the impact of temperature/humidity with dangerous category as illustrated in Figure 2.2.

**Heat Stress Index**

| Danger category | Heat index | Heat syndrome |
|---|---|---|
| IV. Extreme danger | ≥ 54 | Heat stroke or sunstroke imminent |
| III. Danger | 39-53 | Sunstroke, heat cramps or heat exhaustion likely. Heat stroke possible with prolonged exposure and physical activity. |
| II. Extreme caution | 32-38 | Sunstroke, heat cramps or heat exhaustion possible with prolonged exposure and physical activity. |
| I. Caution | 27-31 | Fatigue possible with prolonged exposure and physical activity. |

***Note.*** *Degree of heat stress may vary with age, health and body characteristics.*

| | Relative Humidity | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| Air Temp (°C) | 50 | 54 | >54 | >54 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 49 | 47 | 54 | >54 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 48 | 45 | 53 | >54 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 47 | 44 | 51 | >54 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 46 | 43 | 49 | >54 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 45 | 42 | 47 | 54 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 44 | 41 | 46 | 52 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 43 | 40 | 44 | 49 | >54 | >54 | >54 | >54 | >54 | >54 |
| | 42 | 39 | 42 | 47 | 54 | >54 | >54 | >54 | >54 | >54 |
| | 41 | 38 | 41 | 45 | 51 | >54 | >54 | >54 | >54 | >54 |
| | 40 | 37 | 39 | 43 | 48 | 54 | >54 | >54 | >54 | >54 |
| | 39 | 36 | 38 | 41 | 46 | 52 | >54 | >54 | >54 | >54 |
| | 38 | 35 | 37 | 39 | 43 | 49 | 54 | >54 | >54 | >54 |
| | 37 | 34 | 35 | 38 | 41 | 46 | 51 | >54 | >54 | >54 |
| | 36 | 33 | 34 | 36 | 39 | 43 | 48 | 54 | 54 | >54 |
| | 35 | 32 | 33 | 35 | 37 | 41 | 45 | 50 | 54 | >54 |
| | 34 | 31 | 32 | 33 | 35 | 38 | 42 | 47 | 52 | >54 |
| | 33 | 31 | 31 | 32 | 34 | 36 | 40 | 43 | 48 | 54 |
| | 32 | 30 | 30 | 31 | 32 | 34 | 37 | 40 | 44 | 49 |
| | 31 | 29 | 29 | 30 | 31 | 33 | 35 | 38 | 41 | 45 |
| | 30 | 28 | 28 | 29 | 30 | 31 | 33 | 35 | 38 | 41 |
| | 29 | 27 | 27 | 28 | 29 | 30 | 31 | 33 | 35 | 37 |
| | 28 | 27 | 27 | 27 | 28 | 28 | 29 | 31 | 32 | 34 |
| | 27 | 26 | 26 | 26 | 27 | 27 | 28 | 29 | 30 | 31 |
| | 26 | 25 | 25 | 26 | 26 | 27 | 27 | 27 | 28 | 28 |

**Figure 2.2: Heat Stress Index with Relative Humidity (McDonald, et al., 2008).**

Moreover, Bates & Schneider (2008) investigated the hydration and physiological impacts of heat stress on construction workers in UAE, which has the same climate conditions as Saudi Arabia. Based on their study, under hot weather conditions, the sweat rate is about 0.3 to 1.5 liter per hour. Losing fluids from the human body will increase heart rate of about 10 beats per minute. It also increases the core temperature of the workers. Human body physiological status under extreme weather conditions is affected by multiple factors such as age, nationality, health conditions, clothing, wind speed, humidity … etc. Saudi construction sector involves multinational workers such as Egyptian, Indian, Pakistani, Filipino, Bangladeshi, Sudanese, Syrian and others, where the majority of construction workers are from India, Bangladesh and Pakistan, respectively (Al-Hammad, I. A., 2006). These differences will reflect on workers' physiological responses and behaviors under the same conditions (Bates, et al., 2009). Therefore, in this study, construction workers' ages, nationalities, humidity and health conditions will be taken into consideration. Bates, et al (2009) also investigated the relationship between the hot weather condition/hydration status and the physiological response of construction workers in UAE. They concluded that, interventions and self-space are essential factors for maintaining workers in safe conditions under extreme weather conditions. Recently, Alshebani & Wedawatta (2014) addressed the lessons learned for how construction organizations are able to manage and control the impact of extreme weather conditions in UAE. The authors argued that construction is one of the most vulnerable to climate change. In addition, the hot weather in UAE has direct impact on construction sites; equipment; and workers' health, safety and productivity.

Construction workers' productivity is also an essential factor that is significantly influenced by weather conditions. There were different approaches were addressed under this context. Through introducing a mathematical model representing the impacts of extreme weather conditions (high degrees of temperature and humidity) on productivity levels of construction workers. Koehn & Brown (1985) were able to prove that workers' productivity and safety are significantly affected by hot and humidity weather conditions.

They concluded that construction workers will suffer when temperature is less than -12˚C (10˚F) and more than 43˚C (110˚F). Similar models were also addressed by Zhao, et al. (2009) where the authors stated that working environment considered hot and humid may be dangerous for construction workers when normal living temperature be more than 35˚C (95˚F); working temperature more than 32˚C (90˚F); and relative humidity more than 60%. Recent studies addressed that the maximum normal working temperature for construction workers during performing outdoors activities is 32˚C (90˚F) (Li, et al., 2015).

More investigations in mathematical models that relate construction workers' productivity and weather conditions were addressed by Srinavin & Mohamed (2003). The authors proposed a mathematical model for estimating workers' productivity that consider hot weather conditions and work intensity. Moreover, Gong, et al. (2012) proposed an integrated approach, including monitoring physiological status, sampling, thermal comfort theories and meteorological data for addressing the impact of hot weather conditions on time utilization, in order to improve productivity. Recently, Li, et al. (2015), investigated the impact of high temperature on construction workers, who were performing outdoors activities (rebar activities), by using recorded productivity data (direct, indirect, and idle time) and WBGT (Wet Bulb Globe Temperature) during. The authors argued that, hot weather conditions have a significant impact on construction workers' productivity.

As it is addressed in many literatures, harsh weather conditions have a significant impact on workers' health and safety, as well as their productivity and performance. This impact can be effectively measured based on the vital signs of the workers, which could be monitored continuously. Vital signs monitoring provides good indication for workers' health and safety conditions under extreme weather more accurately than fixed standards and thresholds where there is a significant variation in workers' behaviors and response. Therefore, application of innovative technologies in this field will make a significant leap in this field by providing applicable and reliable sensors for this purpose.

## 2.4 Physiological Status Monitoring Technology

Technology development drives different industries to utilize innovative technologies to serve various purposes. Different innovative technologies have been successfully applied in different fields of the construction industry, such as construction safety and health. They include automation; building information modelling (BIM); data mining; geographic information system (GIS); radio frequency identification (RFID); robotics; sensing technology; and wireless networks (Alam & Ben, 2014). Recently, construction workers' safety and health is considered as one of the most significant concerns of construction organizations, where they try to adopt and apply new technologies to improve construction workers' safety and health (Alam & Ben, 2014).

Application of new technologies in the construction industry is not widely utilized as a result of uncertainties in its application, unavailability of related information about the innovative technologies, as well as benefits and related costs. On the other hand, there is a growth in the number of construction safety researches that addressing the application of new technologies in recent years (Figure 2.3) (Zhou, et al., 2015; and Zhou, et al., 2013). In spite of this increasing in application of new technologies for improving construction safety, there is still a scientific gap in this area of research.

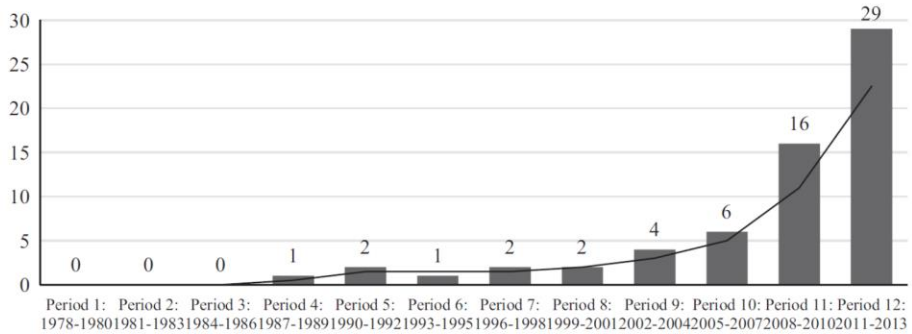


**Figure 2.3: Application of new technologies in construction safety research (Zhou, et al., 2015).**

Physiological Status Monitoring (PSM) is wearable sensors that is attached to a human body to measure and monitor physiological status, body movements and the environmental conditions, and transmit the recorded data to a remote station (U.S. Patent No. US20070299325 A1, 2007). PSM can be defined as a system consists of an array of sensors embedded into the fabric of the wearer to continuously monitor the physiological parameters and transmit wireless to a remote monitoring station. This system includes sensors, installed in wearable shirt or belt, and a remote station for monitoring with a software (Pandian, et al., 2008). The sensors detect heart rate, breathing rate and other vital signs, while the person under measurement is performing his/her activities, and then the sensors transmit the signals to receivers (U.S. Patent No. US20070299325 A1, 2007). The main differences between the physiological status monitoring (PSM) and the conventional versions of this technology, which is available in hospitals, is that the conventional system contains large equipment which make it difficult to be applied in monitoring people continuously while they are performing their activities normally in remote areas (Pandian, et al., 2008).

Most of the PSM technology studies were conducted for both healthy/safety of human and improving productivity purposes. This section discusses different studies that are addressing the application of PSM.

Pandian, et al. (2008) conducted an in-depth literature review about PSM technology and its applications in different field. The authors concluded that, PSM technology is a recommended tool to be applied for human health and safety applications, especially in hazardous tasks e.g. extreme conditions of soldiers, firefighters, mine works etc. In addition, the authors addressed that, there are some concerns about the battery life of PSM sensors and the area that can be cover by the wireless network.

PSM technology has been applied in various industries to monitor workers' safety in regard to various factors such as heat stress (Brake & Bates, 2002). Moreover, it was applied for safety and tracking soldiers for military purpose. To illustrate, of the recent U.S. army reports (Hirschberg, et al., 2014) addressed that, PSM and wearable sensors will be a major part of "Department of Defense" programs that is related to monitoring Warfighter physiological status and the surrounding environment, as well as their health and safety conditions. Similar application of PSM technology were addressed by Matthews, et al. (2007); Buller & Karis (2007); Lim, et al. (2010); and Hirschberg, et al. (2014). In addition, PSM technology was also use as part of NASA researches serving safety purposes, e.g. monitoring Astronauts physiological status under extreme environmental conditions (Montgomer, et al., 2004; and Coleman & Rademakers, 2012). Furthermore, PSM technology was also applied for monitoring health and safety of Firefighter's (Magenes, et al., 2010; Dolezal, et al., 2014; and Salim, et al., 2014); athletes (Wilson, et al., 2011); as well as medical purposes (Kokonozi, et al., 2010; and Malhi, et al., 2012). PSM technology has also been used in researches in construction industry, e.g. Abdelhamid & Everett (2002); Gatti, et al. (2011); Chan, et al. (2012); Gatti, et al. (2012b); Cheng, et al. (2013a); Gatti, et al. (2014a); and Gatti, et al. (2014b).

Most of construction safety and health studies addressed that construction industry is one of the most hazardous industries; therefore, application of new technologies in monitoring and improving health and safety condition become one of the major part of recent construction researches. Different perspectives were addressed with considering both monitoring and improving construction workers' health, safety, ergonomic, productivity, and performance. For instance, Abdelhamid & Everett (2002) proposed an assessment for construction workers activities using PSM technology, in order to identify whether construction workers are performing their tasks within acceptable physiological thresholds. The authors investigated 100 participants of construction workers who were performing normal construction activities. They concluded that, 20 to 40% of construction workers often performing their tasks while their physiological status is not within the acceptable threshold. Therefore, there is a need to apply PSM to improve construction workers healthy and safety. One of major limitations of Abdelhamid & Everett (2002) study is that, the applied technology ("AeroSport KB1-C" and "Polar Vantage XL") involved large sensors that hinder workers' movements, and make them distressed and behaving abnormally as it is shown in Figure 2.4.

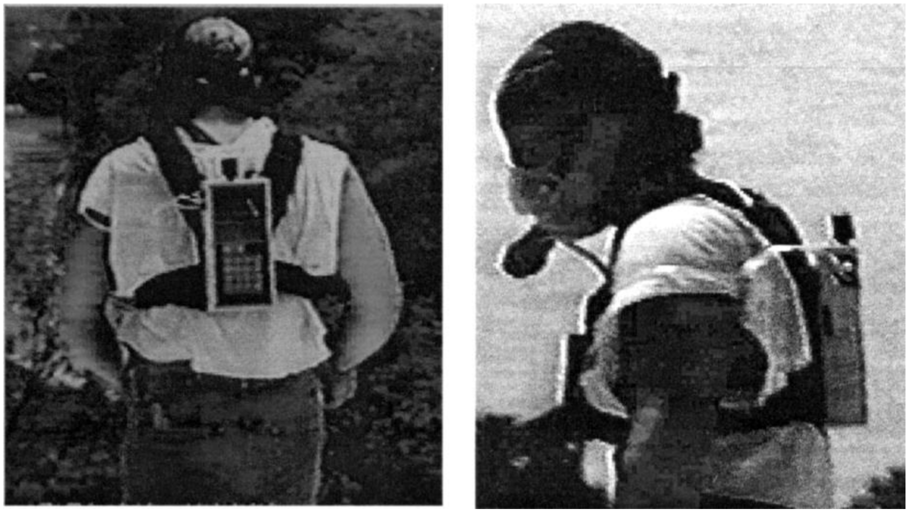

**Figure 2.4: Applied PSM technology in Abdelhamid & Everett (2002) study for PSM.**

In addition, the authors utilized two indicators to measure the physiological status of construction workers which are HR and oxygen uptake level. However, there is some studies considered BR as an indicator for PS of human body under (Koehn & Brown, 1985; and Buller & Karis, 2007). Moreover, Gatti, et al. (2011) addressed the application of PSM technology in assessing construction workers' physical strain in order to improve workers' health, safety and productivity. The authors argued that, most of previous studies, which investigated physiological status of workers in different fields, utilized intrusive and uncomfortable tools which interrupt the normal behavior of the participants while they are performing their tasks. PSM technology, on the other hand, represents an effective tool to monitor construction workers while they are performing their dynamic activities and tasks, without any interruption and discomfort. Similar study was conducted by Gatti, et al. (2012a) where the authors proved that there is significant relation between physical strain and construction workers' productivity by using HR as an indicator for physical strain and productivity such that they proposed a mathematical formula representing the proposed relation which was addressed as a parabolic relation based on the collected data. In addition, they concluded that HR is an accurate measure for physical strain. The major limitation of this study is that the authors kept the weather condition constant by performing the experiments inside a lab. Therefore, the assigned task would not give accurate results, which reflect the real situations in construction sites. These limitations could be eliminated by conducting real construction site experiments. HR, relative HR and BR were also recommended as accurate measures for construction physiological status Gatti, et al. (2014a) .  A further investigation in PSM technology was addressed in Gatti, et al. (2012b) study such that the authors evaluated three different technologies for PSM applications "Zephyr BioHarness (BH), Zephyr HxM, and Hidalgo EQ-01". These technologies have different dimensions, weights, data transaction methods and measured variables (see Table 2.2).

**Table 2.2: Comparison between PSM technologies that are addressed in Gatti, et al. (2012b) study.**

| Name | BH | HxM | EQ-01 |
|---|---|---|---|
| Dimensions (mm) | 80×40×15 | 65×30×12 | 123×75×14 |
| Weight (gm.) | 35 | 16 | 75 |
| Transaction methods | Bluetooth or wireless | Bluetooth | Bluetooth or wireless |
| Measured variables | HR, BR, acceleration in 3D, skin temperature, posture. | HR and acceleration in 3D. | HR, BR, acceleration in 3D, skin temperature, posture. |

The result of Gatti, et al. (2012b) comparison reveals to that, BH and EQ-01 technology provide reliable and effective tools for monitoring physiological status through measuring HR and BR of construction workers without any interruptions to their tasks. More investigation in monitoring construction workers' physiological load was introduced by Li

& Gerber (2012). The authors employed PSM technology to measure HR and energy expenditure with the purpose of assessing different physiological loads of construction workers' tasks to achieve safer working conditions.

Assessing the effects of harsh weather conditions on construction workers' health and safety represents one of the essential applications of PSM technology. To illustrate, Chan, et al. (2012) addressed one of the most successful application of PSM technology by investigation impact of heat stress in construction workers during the hot session in Hong Kong by using a portable metabolic cart (K4b2, COSMED, Rome, Italy). The authors were able to propose a modification in the original model of heat stress. They suggested that more heat stress model could be developed based on researchers' objectives and the proposed variables that is related to construction workers' health and safety. In addition, the authors recommended that there is a need for conducting more investigation in heat stress impact on construction workers who are performing their tasks under extreme weather conditions with taking in account different countries to enhance the general view of heat stress. However, in their study, Chan, et al. (2012) used bulky sensors to monitor workers, which made the participants behave abnormally while performing their activities as it is illustrated in Figure 2.5.

**Figure 2.5: Applied PSM technology in Chan, et al. (2012) study for heat stress monitoring.**

A further instigation in hot weather impact on construction workers by using PSM technology (portable metabolic cart (K4b2, COSMED, Rome, Italy)) was introduced by Wong, et al. (2014). The authors compared hot weather impact on the physiological responses of both bar benders and fixers. They concluded that, bar fixers showed higher physiological response than the benders under the same weather conditions. There are few studies addressing the application of PSM technology in Arabian Gulf's construction sectors for both improving health and safety conditions in addition to improving workers' productivity. For example, Bates & Schneider (2008) addressed construction workers' physiological response under harsh weather conditions (extreme weather) in UAE. The authors utilized Polar S720i to measure HR of the participated workers in order to assess the physiological fatigue that is resulted from heat stress. The authors concluded that, UAE's construction workers can perform their tasks under hot weather without any risk on their health, if they get hydrated sufficiently in addition to working with self-pace. In addition, Bates & Schneider (2008) argued that, the well-known standards for assessing high temperature risk in such region (Arabian Gulf Countries) do not provide practical measures, especially in construction industry where workers are exposed to extreme weather conditions and dynamic activities. Therefore, addressing extreme weather impacts on construction works needs more investigation.

Moreover, PSM technology was recommended to be applied to monitor works health and safety conditions under harsh weather conditions, such weather conditions in Arabian Gulf Countries. Alam & Ben Hamida (2014) suggested some areas for PSM application in order to solve health and safety problems in construction sectors by utilizing PSM technology in assessing unsafe environmental and activities conditions; physiological load and strain; tracking workers in unsafe locations to warn them; protecting workers from toxic gases; and other applications. In detailed, the authors argued that, PSM technology can be applied in monitoring the impact of the surrounding environmental conditions such as “pressure, heat, humidity, light intensity and carbonic gases”. A further investigation in monitoring the impact of hot and humid weather conditions on construction workers was conducted by Lee & Migliaccio (2014) such that the authors were able to determine the acceptable physiological zones and HR bounds based on the recorded data of HR during real construction experiments. The authors argued that PSM technology is an effective tool to prevent injuries and illness in construction industry. It also good indicators for safety level to help safety management in identifying hazardous working conditions and rest periods in addition to tasks assignment. Lee & Migliaccio (2014) conducted their experiment under hot temperature, where maximum degree was 65.3°F (18.5°C) which is considered as cold weather in Arabian Gulf Countries in which maximum temperature may be greater than 135°F (45°C) and humidity level may higher that 90% (Joubert, et al., 2011).

Recently, Migliaccio, et al. (2012) applied PSM with real-time worker location sensing (RTLS), which is an Ultra-Wideband (UWB) technologies, in order to assess physiological and ergonomic status of construction workers who were performing indoors bending activities. Similar approach was followed by Cheng, et al. (2013a), where the authors proposed one of the most recent applications of PSM technology in construction industry as an integrated tool with "(RTLS devices in order to measure and monitor ergonomic status of safe/unsafe construction workers' activities. Migliaccio, et al (2012) and Cheng, et al. (2013a) were able to identify the unsafe workers' activities ergonomically based on the integration of the collected data from PSM, UWB and video records. In addition, those authors argued that PSM and UWB technologies provide satisfactory reliable tools for continuous wireless monitoring of construction workers.

Furthermore, PSM technology was successfully applied in assessing construction workers' productivity and performance. To illustrate, Cheng, et al, (2013b) proposed an integrated system (PSM, UWB and video records in lab experiments) for monitoring construction workers in order to measure their productivity. The authors concluded that, PSM technologies are an effective tool to measure construction workers' physiological status, workers position, posture and workers' activity as well as productivity. In addition, they supported the argument that, the recorded data from different sensors (PSM and GPS) can be integrated effectively with real time video records.

Moreover, Gatti, et al. (2014a) proposed a formula describing the relationship between physical strain, measured by HR, relative HR and BR, and the resulted productivity of construction workers. The authors argued that, HR and relative HR are effective indicators for productivity unlike BR, which could not be good indicator for productivity level. Gatti, et al. (2014a) conducted their study in a lab, which focused on indoors activities without considering change in environmental conditions (temperature and humidity) as well as work pressure in construction sites. PSM applications in construction industry still need more investigation to cover different activities, nationalities and construction types in different regions. Lee, et al. (2015) supported the validity of HR as an efficient tool for measuring physiological strain in construction industry. Using Zephyr technology, they argued that, PSM technology is reliable and applicable technology for monitoring health and safety conditions of construction workers. Both PSM's parameters (HR and BR) were addressed in Gatti, et al. (2014b) study, such that the authors compared two different available tools: BioHarness BT 1 (BH-BT) manufactured by Zephyr Technology Corporation (Annapolis, MD, USA); and Equivital EQ-01 (EQ-01) manufactured by Hidalgo Ltd (Swavesey, UK). Both sensors were used for assessing physiological status of construction workers with consideration of common static and dynamic activities. The authors concluded that, for monitoring ergonomic physiological conditions, BH-BT is an appropriate tool for measuring HR at both resting/working periods and BR at resting periods. On the other hand, EQ-01 is not appropriate for measuring HR at working period and BR at both resting/working periods. In addition, the authors supported PSM technology as a reliable to for monitoring construction workers.

Recently, there are several studies that addressed the application of PSM technology in construction industry. For instance, Yi, et al. (2016a) proposed a new system for early-warning that applied in construction industry for continuums monitoring of heat strain conditions for construction workers under hot and humid weather conditions and give warning signs to the smart phones. However, this study included large sensors that could hinder normal activities of the construction workers. In addition, the conducted measurements were taken place in Hong Kong where maximum degree of temperature reach to 34 °C in during the hottest sessions which is considered as moderate weather conditions compared to the Saudi weather conditions.  Later, this study was extended to include an assessment of two new designs for construction workers' uniform in order to identify which one is more appropriate for them under hot and humid weather simulated conditions by applying the PSM technology and physiological responses. The authors argued that the proposed designs will help reducing the impact of hot and humid weather conditions on construction workers (Yi, et al., 2016b). Moreover, Lee and Migliaccio (2016) addressed the application of PSM technology for assessing the physiological strain of concert workers with comparison with other workers in construction industry. The authors conducted real site measurements including five different workers in the summer and the autumn. They concluded that concrete and steelwork workers have the same physiological records and vehicle assembly activities show lower physiological records than concrete activities. Some agricultural work activities show higher lower physiological records than concrete activities.

Table 2.3 summarizes the previous researches that had been conducted in construction industry with regard to PSM application for workers' health, safety, ergonomics, productivity and performance monitoring.

**Table 2.3: Summary of (PSM application in construction industry) previous researches.**

| Date | Authors | Application | In/Outside Arabian Gulf Region | Applied Technology | Site/Lab Experiments |
|---|---|---|---|---|---|
| 2002 | Abdelhamid & Everett (2002) | Physical performance | Outside the Arabian Gulf | AeroSport KB1-C" and "Polar Vantage XL | Outdoors and indoors activities |
| 2006 | Roja, et al. (2006) | Workers health and ergonomic risks | Outside the Arabian Gulf | POLAR S810i™ | Construction site experiments |
| 2008 | Bates & Schneider (2008) | Hot weather impact | In UAE | Polar S720i | Construction site experiments |

**Table 2.3: Summary of (PSM application in construction industry) previous researches.**

| Date | Authors | Application | In/Outside Arabian Gulf Region | Applied Technology | Site/Lab Experiments |
|---|---|---|---|---|---|
| 2011 | Gatti, et al. (2011) | Workers health, safety and productivity | Outside the Arabian Gulf | BH-BT; HxM (Zephyr technology) and Hidalgo EQ-01 | Lab experiments |
| 2012 | Gatti, et al. (2012a) | Physical strain and productivity | Outside the Arabian Gulf | Zephyr Technology | Lab experiments |
| 2012 | Gatti, et al. (2012b) | Physical strain and productivity | Outside the Arabian Gulf | Zephyr BioHarness (BH), Zephyr HxM, and Hidalgo EQ-01 | Lab experiments |
| 2012 | Li, & Gerber (2012) | Physiological load, energy expenditure and safety | Outside the Arabian Gulf | HR (a chest strap & a wrist watch), energy expenditure (sensor is tied to the arms of the test participants) | Lab experiments |
| 2012 | Chan, et al. (2012) | Weather conditions impact (hot weather) | Outside the Arabian Gulf | Portable metabolic cart "(K4b2, COSMED, Rome, Italy)". | Construction site experiments |
| 2012 | Migliaccio, et al. (2012) | Physical strain, ergonomics and location | Outside the Arabian Gulf | Zephyr Technology and "real-time worker location sensing (RTLS)" (Ultra-Wideband (UWB)) | Lab experiments |
| 2013 | Cheng, et al. (2013a) | Physical strain, ergonomics and location | Outside the Arabian Gulf | Zephyr Technology and "real-time worker location sensing (RTLS)" (Ultra-Wideband (UWB)) | Lab experiments |
| 2013 | Cheng, et al. (2013b) | Productivity and activity/task analysis | Outside the Arabian Gulf | Zephyr Technology and "real-time worker location sensing (RTLS)" (Ultra-Wideband (UWB)) | Lab experiments |
| 2014 | Gatti, et al. (2014a) | Physical strain and productivity | Outside the Arabian Gulf | Zephyr Technology | Indoors simulated activities |
| 2014 | Gatti, et al. (2014b) | Two PSM technologies validation (Zephyr technology is recommended) | Outside the Arabian Gulf | Zephyr and Equivital EQ-01 (EQ-01) Technology | Lab experiments |
| 2014 | Lee & Migliaccio (2014) | Weather conditions impact (hot and cold weather) | Outside the Arabian Gulf | Zephyr Technology | Construction site experiments |
| 2014 | Wong, et al. (2014) | Hot weather impact | Outside the Arabian Gulf | Portable metabolic cart (K4b2, COSMED, Rome, Italy)". | Construction site experiments |
| 2015 | Lee, et al. (2015) | Physical strain, performance and environmental factors | Outside the Arabian Gulf | Zephyr Technology | Construction site experiments |

**Table 2.3: Summary of (PSM application in construction industry) previous researches.**

| Date | Authors | Application | In/Outside Arabian Gulf Region | Applied Technology | Site/Lab Experiments |
|---|---|---|---|---|---|
| 2016 | Yi, et al. (2016a) | Impact of heat strain conditions on construction workers. | Outside the Arabian Gulf | Portable metabolic cart "(K4b2, COSMED, Rome, Italy)". | Construction site experiments |
| 2016 | Yi, et al. (2016b) | Impact of hot and humid weather conditions on construction workers. | Outside the Arabian Gulf | "(CorTemp™, HQInc., Palmetto, Florida, USA)" and "(NTC-resistant temperature matched thermistors ACC-001, Rhopoint Components Ltd, UK)" | Lab experiments |
| 2016 | Lee and Migliaccio (2016) | Assessing the physiological strain of concert workers with comparison with other workers in construction industry | Outside the Arabian Gulf | Zephyr BioHarness™ 3 | Construction site experiments |

Table 2.3 illustrates that, only five PSM construction studies addressed the impact of harsh weather conditions on construction workers' health, safety and performance. In addition, only five studies were conducted in real construction sites, which only one of them was conducted in Arabian Gulf region (UAE). Moreover, Zephyr technology is the most applicable and recommended technology for monitoring physiological status of construction workers.

Based on the PSM application in construction previous researches, there are scientific gaps in conducting PSM studies in regard to harsh weather conditions, real construction application, as well as conducting studies inside Arabian Gulf Countries which considered one of the hottest area in the world where maximum degree of temperature may be greater than 135°F (45°C) and humidity level may be higher that 90% (Joubert, et al., 2011)). In addition, different nationalities of construction workers and different types of activities (indoors and outdoors activities) should be considered in future studies. All these perspectives will be considered in this study by conducting real construction site measurements. In addition, a valid, applicable and recommended technology of PSM will be utilized to conduct real construction experiments.

- **Zephyr Technology**

There are several technologies can be used for PSM purposes. According to Alam & Ben Hamida (2014), there are 41 different wearable sensors available in the market for medical applications, 77 for fitness applications, 117 for lifestyle monitoring and 26 for entertainment. In this section, we will address the previous works that have been conducted in PSM by using Zephyr technology for different purposes, in order to demonstrate the applicability, reliability and accuracy of this technology.

"Zephyr" (Annapolis, Maryland, USA) is a leading global provider of healthcare products, and it is recognized innovator in patient monitoring and respiratory care devices. This technology is directed toward physiological status monitoring in training applications and in high stress environmental conditions. In addition, it was successfully applied in some researches that are cooperated with Fire Department, NASA Ames Research Centre, National Guard Civil Support Teams, and multiple US Special Forces contracts. All this researches supported and validated the application of Zephyr™ technology under extreme operating environmental conditions (Zephyranywhere (About Zephyr), 2015). The main tool applied for PSM is BioHarness™ 3, which is available in different forms based on the way of contact with human body (compression shirt, chest strap and holder) as it is illustrated in Figure 2.6. In addition, there are another tools are provided by Zephyr™ such as HxM™ BT, which mostly used for fitness monitoring.

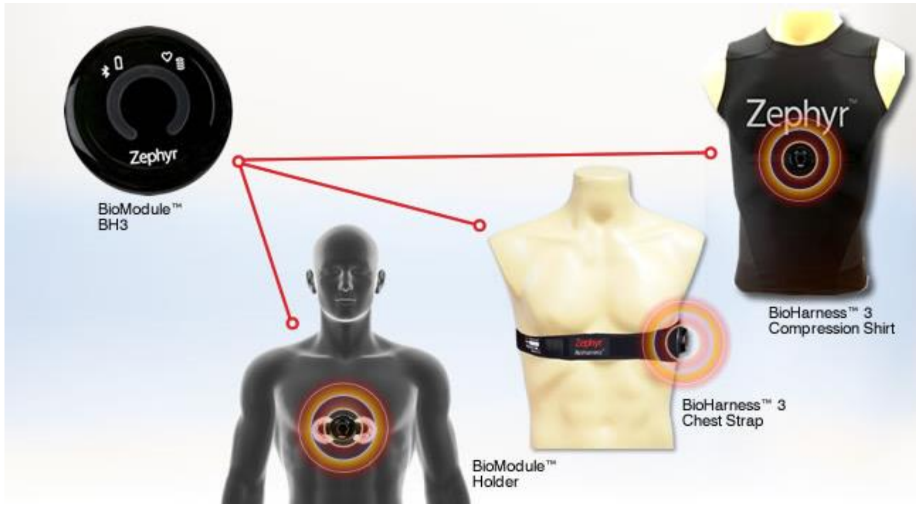


**Figure 2.6 Different available types of BioHarness™ 3 (Zephyranywhere (About Zephyr), 2015).**

Zephyr website addressed several applications of their technology in various disciplines, such as sports, medical and other applications. These studies are summarized in the following Table 2.4.

**Table 2.4: Summary of Zephyr technology application in different fields.**

| Date | Authors/ organization | Application | Reference | Note | Field |
|---|---|---|---|---|---|
| - | Stanford University | Monitoring health and physiological status. | Zephyr Website (2015) | Case study | Sport |
| - | 32nd Maryland Civil Support Team (CST). | Monitoring the physiological during. | Zephyr Website (2015) | Case study | Military |
| - | "Centre for Human Factors Research (COHFE)", New Zealand | Monitoring health and safety conditions of "Firefighters and Loggers" | Zephyr Website (2015) | Case study | Firefighters |
| 2007 | Human Performance Lab at Stanford University | Monitoring athletes performance during New York City Marathon | Zephyr Website (2015) | Case study | Sports |
| 2008 | Zephyr Technology | Validation the Zephyr BioHarness's recorded data of HR | Zephyr Reports (Validity of BioHarness™ Heart Rate vs 3-lead ECG, 2008) | Technical Report | Validity test |
| 2009 | Pantelopoulos, & Bourbakis, (2009) | Remote health monitoring for medical purposes | 21st IEEE International Conference on Tools with Artificial Intelligence. IEEE | Published Conference | Medical |

**Table 2.4: Summary of Zephyr technology application in different fields.**

| Date | Authors/ organization | Application | Reference | Note | Field |
|---|---|---|---|---|---|
| 2009 | Myers, & Downs, (2009) | Cognitive fatigue prediction. | Springer International Publishing AG | Published Conference | Medical |
| 2009 | Pike Township Fire Department training scenarios, Indianapolis, Indiana (2009) | Testing Zephyr BioHarness's data quality, communications quality and reliability | Zephyr Reports (2009) | Technical Report | Firefighters |
| 2010 | Prince George's County Fire/EMS Department | Monitoring the physiological, health and vital conditions during fire rescue test. | Zephyr Website (2015) | Case study | |
| 2010 | Lerer, et al. (2009-2010) | Monitoring health and fatigue conditions of ice hockey players. | Zephyr Website | Philadelphia, PA, Senior Design Project | Sport and health |
| 2010 | Chilean Rescue Team. | Rescue operations of miners' workers who were trapped in Chile. | Zephyr Website (2015) | Case study | Accident and Health. |
| 2010 | NASA Ames | Monitoring Astronauts physiological conditions and health during zero gravity NASA test. | Zephyr Website (2015) | Case study | NASA |
| 2010 | Kokonozi, et al. (2010) | Monitoring health conditions of cardiac patients. | Computing in Cardiology, IEEE | Published Conference | Health |
| 2010 | Cinaz, et al. (2010) | Assessing mental workload resulted from daily normal office work activities. | Springer International Publishing AG | Published journal | Health and occupational researches |
| 2013 | Cinaz, et al. (2013) | | Zephyr Website | Published journal ACM UbiComp | |
| 2011 | RW Wilson, et al. (2011) | Identifying physiological thresholds during athletes training experiments. | Journal of strength and conditioning research | Published journal | Sport and health |
| 2011 | Atrash, et al. (2011) | Monitoring physiological status in exercise experiments. | AAAI Spring Symposium: Computational Physiology | Published Conference | Sports and health |

Recently, Zephyr technology was recommended in several studies as a valid tool for PSM of construction workers. To illustrate, Gatti, et al. (2011) assessed the reliability and accuracy of collected date of HR and acceleration by Zephyr technology during recording dynamic activities of construction workers. They concluded that, Zephyr technology is a recommended technology for construction safety applications. A further application for Zephyr technology ("BioHarness BT") was addressed by Gatti, et al. (2012a) for monitoring HR of construction workers in a lab-setting experiment, to identify physical strain level based on HR recorded data. Based on the result of Gatti, et al. (2012b), Zephyr technology is considered as an effective technology for monitoring health and safety conditions of workers in construction industry. It accurately and effectively measures HR in a dynamic nature of their tasks as well as their environmental conditions, without any interruption or hindrances. Furthermore, Migliaccio, et al. (2012) were able to assess physiological and ergonomic status of bending activities of construction workers where the authors incorporated the UWB PSM recorded data of construction workers by using Zephyr sensors. The authors concluded that Zephyr technology is reliable tool for monitoring construction activities remotely. This conclusion was also supported by Cheng, et al. (2013a) , (2013b).

In another study, Gatti, et al. (2014a) utilized Zephyr technology in construction physical strain assessment. They recommended HR, relative HR and BR as effective measures for physical strain. Furthermore, Gatti, et al. (2014b) validated Zephyr technology (BioHarness BT 1) as an effective tool for monitoring physiological and ergonomic status of construction workers in both static and dynamic activities. The authors argued that, Zephyr technology provides valid records for physiological status (HR) in both dynamic and static activities.

Another field of Zephyr technology application in construction industry was addressed in Lee & Migliaccio (2014) study, where the authors utilized Zephyr BioHarness™ 3 in assessing the impact of hard weather conditions on construction workers health and physiological conditions. Recently, Lee, et al. (2015) addressed that, Zephyr BioHarness™ 3 chest belt is the most accurate and applicable tool for monitoring physiological status of construction workers while they are performing their tasks without any interruption or inconvenience. It is important characteristic for effective PSM tools to contain a warning system for detecting vital signs of the subjects under study (Buller & Karis, 2007). This character is available in Zephyr BioHarness™ 3 technology, where it gives warning signs through producing different warning sounds and lights.

To summarize, Zephyr technology provides accurate, reliable and valid real-time records for construction workers while they are performing their normal tasks, without creating any interruption or discomfort.

There is a trend toward adopting innovating technologies for enhancing construction workers' safety and health. This literature review chapter discusses 16 published researches addressing the application of innovative technologies, such as PSM technologies, in this area. These studies were conducted in different locations around the world, and only one study was conducted in Arabian Gulf Region (UAE). These studies mostly assessed work load and fatigue, as well as workers' performance and productivity levels. In addition, there are four published studies addressing the application of PSM in assessing the impacts of harsh weather conditions in construction workers, which one of them was conducted in UAE by using "Polar S720i" sensors. Different monitoring sensors and technologies were employed in PSM applications in construction industry as it is illustrated in Table 2.3. It can be derived from this table that the most important factor for getting a successful application of this technology are size, applicability and reliability of the utilized sensors, and it should not hinder or interrupt workers performing the required tasks and activities. In summary, there is a scientific gap in applying PSM technology in assessing impacts of harsh weather conditions Saudi Arabia which considered one of the hottest area in the world with considering the utilization of applicable and reliable sensors.

## 2.5 Physiological Status Monitoring Technology in Arabian Gulf

Construction safety in Saudi Arabia gets attention from construction and governmental organizations as well as researchers. This attention is driven by economic growth and intense competition between Saudis construction companies, in order to achieve high levels of productivity and performance (Al Haadir & Panuwatwanich, 2011). This section reviews different construction studies that have been conducted in Saudi Arabia in order to identify the scientific gap.

To illustrate, Jannadi, M. O. (1995) investigated the impact of construction workers' relationship on the safety level in Saudis construction sector. The results reveal that construction workers have significant impact on safety level. Moreover, Al Haadir & Panuwatwanich (2011) applied two different approaches (Analytical Hierarchy Process AHP and Pareto) in order to identify the most significant factors that affecting the success of safety programs application in Saudis construction sector. This study concluded that, the success of safety programs implementation mainly depends on management support; stated objectives; workers' attitudes; teamwork; effective implementation; training; and effective supervision. A further investigation by Alasamri, et al. (2012) addressed safety culture improvement framework, which is based on key elements of safety culture (safety climate, management system, behavior and organization). In addition, the authors argued that this framework can be used as an indicator for contractors' safety culture statue. Moreover, there are several studies addressed accidents and risks assessment and analysis in Saudi construction sector. For example, Jannadi & Al-Sudairi (1995) evaluated different safety programs that are applied in different construction companies in Eastern Province- Saudi Arabia; Al-Utaibi, M. A. (1996) investigated the relationship between building construction projects size and the resulted safety level; Jannadi & Assaf (1998) proposed an assessment for safety procedures in Saudis construction sites with considering projects' size; Walker & Maune (2000) addressed a special case of injuries-free project (Saudi Chevron Petrochemical) in Saudi Arabia; Jannadi & Bu-Khamsin (2002) addressed factors affecting in safety performance of Saudis contractors; Jannadi & Almishari (2003) proposed a computerized model for identifying risks and its severity, exposure and probability; Jannadi, O. A. (2008) addressed risks related to trenching and excavation activities; Al Haadir & Panuwatwanich (2011) addressed the influential factors that have major impacts on achieving effective safety programs application in Saudi Arabia; and Al-Haadir, et al. (2013) suggested a conceptual safety model for Saudis construction sector safety.

The steady growth in construction sectors of Arabian Gulf Countries, however, is associated with increasing number of construction accidents (Al-Kaabi & Hadipriono, 2003). Different studies had been conducted in Arabian Gulf countries with considering different perspectives. To illustrate, Al-Kaabi & Hadipriono (2003) addressed the reasons of low safety performance of UAE's construction sector; Joubert, et al. (2011) proposed some prevention actions to prevent works from high degrees of temperature in UAE; and Borthwick & McAndrew (2012) investigated the effectiveness of the existing safety provisions and standards in UAE's construction sector.

Different studies on construction safety that have been conducted in Saudi Arabia or in Arabian Gulf countries are summarized in Table 2.5 and

Table 2.6.

**Table 2.5: Summary of construction safety studies in Saudi Arabia.**

| Date | Author | Objectives | Results | Methodology |
|---|---|---|---|---|
| 1995 | Jannadi, M. O. (1995) | Investigating the impact of workers' relationships and resulted safety in the construction sites. | Safety level in the construction sites is highly influenced by workers' relationships. | Survey based |
| 1995 | Jannadi & Al-Sudairi (1995) | Evaluating different safety programs that are applied in different construction companies in Eastern Province. | Adopting high safety standards and effective training programs make large construction companies safety levels better than smaller companies. | Survey based |
| 1996 | Al-Utaibi, M. A. (1996) | Addressing the correlation between accidents rate and construction site safety levels in addition to the impact of middle management practices. | The author suggested some recommendations for improving safety level in building construction projects. | Survey based |
| 1998 | Jannadi & Assaf (1998) | Assessing different safety procedures in Saudis construction sites. | Construction safety level depend on projects' size. Such that large projects have higher score in the proposed assessment. | Survey based |
| 2000 | Walker & Maune (2000) | Addressing a special case of injuries free project in Saudi Arabia. | Management support and committeemen create safer culture and climate | Case study |
| 2002 | Jannadi & Bu-Khamsin (2002) | Investigating factors affecting in safety performance of Saudis contractors. | Identifying 20 significant factors and 85 sub-factors with identifying their significant level. | Survey & interviews based |
| 2003 | Jannadi & Almishari (2003) | Evaluating and assessing major risks that are related to different construction activities. | Proposed a computerized model for identifying risks and its severity, exposure and probability. | Survey based |
| 2004 | Jannadi & Al-Utaibi (2004) | Investigation the relation between project size and safety level. | There is a positive relation between projects size and safety level. | Survey based |
| 2004 | Meo, S. A. (2004) | Investigating the impact of cement dust on construction workers. | Preventive measures and procedures are required in order to minimize cement dust risk. | Medical study |
| 2008 | Jannadi, O. A (2008) | Identifying trenching associated risks. | Enhancing safety through providing required equipment, protection and training with taken in account effective site measurements. | Survey based |
| 2011 | Al Haadir & Panuwatwanich (2011) | Application two different approaches ("Analytical Hierarchy Process AHP" and Pareto approach) in order to identify the significant factors affecting on the success of safety programs in Saudis construction sector. | The success of safety programs implementation mainly depends on management support; stated objectives; workers' attitudes; teamwork; effective implementation; training; and effective supervision. | Survey based |
| 2013 | Al-Haadir, et al. (2013) | Developing an integrated model that interrelates three different factors related to construction safety which are motivation, climate and behavior. | Safety climate playing a major role by connecting between motivations and resulted behaviors. | Survey based |
| 2013 | Meo, et al. (2013) | Investigating different musculoskeletal symptoms in construction workers in Saudi's construction sector. | Different musculoskeletal symptoms were identified in different part of workers' body (neck; shoulder; upper and lower back; legs; feet; head heaviness; and body fatigue). | Clinical interview & questionnaire |

**Table 2.6: Summary of construction safety studies in other Arabian Gulf Countries.**

| Date | Author | Objectives | Results | Methodology |
|---|---|---|---|---|
| 1990 | Ezz Al.Din M.A. (1990) | Addressing the relationship between work presser and control in construction sites with the resulted safety level. | The study suggested some recommendations for enhancing the safety of construction sites in Kuwait. | Survey based |
| 1998 | Kartam & Bouz (1998) | Investigating construction accidents/injuries in Kuwaiti construction sector. | Construction sector in Kuwait is the most hazardous sector. | Interviews & safety reports |
| 2000 | Kartam, et al. (2000) | Evaluating safety regulations and procedures that have been adopted by owners, designers and contractors as well as insurance companies in Kuwait. | Labor, accidents/injuries recording system, large numbers of subcontracting, safety regulations, priority of safety, construction companies' size, "competitive tendering" and harsh weather conditions are the major problems facing construction safety in Kuwait. | Survey & Interviews |
| 2002 | Al-Tabtabai, H. M. (2002) | Identifying the causes of construction accidents in Kuwait. | Management related practices are the most effective causes of construction accidents in Kuwait. | Survey based |
| 2003 | Al-Kaabi & Hadipriono (2003) | Conducting an assessment for safety performance of UAE's construction companies. | Insufficient workers' benefits; workplace orientation; protection aids and preventive actions; health conditions and hygiene are the most influential factors causing poor softy performance. | Survey & Interviews |
| 2008 | Bates & Schneider (2008) | Hot weather physiological impact in construction workers in UAE. | Sufficiently hydrated workers can work under hot weather conditions with considering. | Site experiment |
| 2009 | Bates, et al. (2009) | Investigating the impact of extreme hot weather on the hydration status of construction and other manual workers in middle east. | Planning resting period is essential step to reduce the impact of extreme weather conditions and for keeping hydration within the safe levels. | Site experiment |
| 2010 | Al-Humaidi & Tan (2010) | Investigating different construction accidents perspectives (type; resulted injuries; at which part of the injured worker's body; accidents results) in Kuwait's construction sector | Construction industry is the most hazardous field in Kuwait and the statistics reveal that there is highly need to improve the current practices. | Accidents reports |
| 2011 | Joubert, et al. (2011) | prevention actions to prevent works from high degrees of temperature in UAE | Prevention action may reduce the illness that is related to heat by almost 50-79.5% | Survey & statistics |
| 2012 | Borthwick & McAndrew (2012) | Investigating the effectiveness of the existing safety provisions and standards in UAE's construction sector. | Safety provisions and standards personal perceptions are influenced by where they live and their culture. | Survey based |
| 2013 | Saidani, et al. (2013) | Addressing the current situation of health and safety performance of construction sector. | UAE's construction companies give more attention to the cost than health and safety performance. Preventive measures planning a major role in improving construction sites' health and safety conditions. | Survey & Interviews |

From Table 2.5, it can be seen that most of the safety studies conducted in Arabia Gulf region addressed construction safety based on the managerial perspectives such as workers relationships; safety programs; management practices …etc. Those studies used mostly questionnaire surveys, in which the results of are mainly depend on human judgment rather than direct measurement. Only three published studies addressed the impact of harsh weather condition on construction workers' health and safety in Arabian Gulf region. It can be concluded that there is a scientific gap in addressing the impact of harsh weather conditions in Arabian Gulf region by conducting real construction sites measurements and observations, as well as utilization the innovative technologies.

## 2.6 Conclusion

Construction workers are considered a valuable resource in construction industry. They are the core factors of performing different activities and tasks. Therefore, their health and safety have become the focus of attention of researchers, leading them to conduct large number of studies addressing this topic. One of the most important topic that has been identified in the literature is on impacts of hard weather conditions on construction workers' health and safety. Many studies discuss the importance of this topic and the need for a conducting more investigation, especially in very/extremely hot regions, such as Saudi Arabia. However, those studies did not take in account practical measurements and observations for assessing the impacts of these factors. As a result of technological development in monitoring and sensing technologies, researchers directed their studies toward the application of innovative technologies in enhancing the applicability, reliability, and profitability of adopting such technologies in enhancing construction workers' health, safety, and productivity. Under this context and based on the literature review, it can be concluded that there are scientific gaps in:

1. Conducting practical measurement and observations for assessing impacts of hard weather conditions on construction workers.

2. Addressing impacts of harsh weather conditions on construction workers in the context of Saudi construction industry.
3. Utilizing PSM technology in enhancing health and safety of construction workers in the context of Saudi construction industry.

# CHAPTER 3

# RESEARCH METHODOLOGY

This chapter addresses detailed description about research problem and related research questions. Then, the selection of the research method will be explained. In addition, this chapter will include research scope and limitations of the proposed study and the research contributions.

## 3.1 Research Problem

It is important to measure the impact of weather conditions (temperature and humidity) in construction sites, in order to ensure that workers are working within the acceptable limits, such as those stated in OSHA standards. Adopting fixed limits and thresholds is not recommended in very/extremely hot regions (Bates & Schneider, 2008). Therefore, continuous monitoring and real-time monitoring systems of construction workers' conditions is important in order to achieve safer working environment in very/extremely hot working conditions (McDonald, et al., 2008; and Kjellstrom, et al., 2009). The Arabian Gulf weather conditions is considered as one of the hottest weather in the world (Joubert, et al., 2011), where maximum temperatures may reach to 45°C or higher and humidity level may be higher than 90% (Joubert, et al., 2011). Based on the literature, there is a scientific gap in addressing impacts of extremely hot weather conditions on construction workers' health and safety in Saudi Arabia.

PSM technology represents an effective tool for assessing construction workers' health and safety with considering different factors, such as remote and continuous monitoring; applicability; reliable records; small size; dynamic activates … etc. This technology has been successfully utilized in different fields, such as for: military applications (Matthews, et al., 2007; Buller & Karis, 2007; Lim, et al., 2010; and Hirschberg, et al., 2014); NASA applications (Montgomer, et al., 2004; and Coleman & Rademakers, 2012); Firefighters health and safety (Magenes, et al., 2010; Dolezal, et al. 2014; and Salim, et al., 2014); athletes (Wilson, et al., 2011); manufacturing (Brake & Bates, 2002); medical purposes (Kokonozi, et al., 2010; and Malhi, et al., 2012); and the construction industry applications . There is a need for investigation of PSM applications in the construction industry in regard to impacts of extremly hot weather conditions on workers health and safety, especilally in Saudi Arabia and other Arbian Gulf countries. Based on the literature, there are different tools and technolgies employed in PSM for serving different purposes (Alam & Ben Hamida, 2014). However, only few of them have been employed in the construction industry due to the dynamic of activities and the nature of construction workers' tasks. Most of the tools, which have been used, hindered workers' movements as well as normal workers' behaviors. Zephyr™ technology represents a good tool for monitoring construction workers. It provides reliable and accurate records for dynamic activities of construction workers without any interruption or discomfort (Gatti, et al., 2011; Gatti, et al., 2012a; Migliaccio, et al., 2012; Gatti, et al., 2012b; Cheng, et al., 2013a; and Cheng, et al., 2013b; Gatti, et al., 2014a; Lee & Migliaccio, 2014; and Lee, et al., 2015). Despite of large number of studies in Zephyr™ technology application in construction industry, there is a scientific gap in employing this technology in investigating impacts of extremely hot weather conditions on construction workers, in particular in the context of the Saudi construction industry. The majority of construction workers in Saudi Arabia are foreigners and they may not be familiar with such extremely hot weather conditions. Different workers may have different levels of extreme weather effects. In addition, physical parameters and the type of assigned tasks are also considered effective factors on workers' response under extreme weather conditions.

Impacts of harsh weather conditions on construction workers need more investigations, especially in Arabian Gulf Countries. This study will address the impacts of harsh weather conditions on construction workers in Saudi Arabia by using physiological status monitoring (PSM) technology that is provided by Zephyr technology. This study was conducted through implementing real construction site measurements.

Through conducting this study in Saudi Arabia, the following research questions could be answered:

1. Is there significant difference in workers' behaviors and responses, who are working in the same conditions?
2. What are the acceptable physiological bounds and heart rate zones for the construction workers under the cases under study?
3. Is it suitable to adopt practical working thresholds for construction workers?

## 3.2 Selection of Research Method

The proposed study was conducted using quantitative approach. The main reason is that questionnaire survey based studies do not give accurate assessments for extremely hot weather conditions impacts. Questionnaire survey depend mainly on human judgments.

They do not provide direct quantitative assessments for the impacts of extremely hot weather conditions on construction workers' health and safety. Direct and continuous monitoring of workers' physiological conditions could provide an accurate indication and warning sign in a case that workers are exposed to dangerous working conditions.

## 3.3 Description of the Selected Research Methodology

This section discusses the tools and methods that were employed in this study, in order to achieve the stated objectives and expected outcomes. The following figure describes research design and steps.

**General Statement**

- **Health and Safety Impacts of Extreme Weather Conditions on Construction Workers.**

**Comprehensive Literature Review**

- **<u>Literature Review:</u>**
  - Construction Workers Health and Safety.
  - Heat and Humidity Impacts.
  - PSM Technology: Zephyr Technology.
  - Construction Safety in SA.

**Scientific Gaps**

- **<u>Scientific Gaps:</u>**
  - Addressing impacts of extreme weather conditions on construction workers in Saudi Arabia.
  - Utilization PSM technology in enhancing health and safety of construction workers in Saudi Arabia.
  - Conducting practical measurements and observations for assessing impacts of extreme weather conditions on construction workers in Saudi Arabia.

**Problem Identification**

- **<u>Problem Statement.</u>**
- **<u>Research Questions:</u>**
  - Is there a significant difference in workers' behaviors and responses, who are working in the same conditions?
  - What are the acceptable physiological bounds and heart rate zones for the construction industry under study?
  - Is it suitable to adopt practical working thresholds for construction workers?

**Research Methodology**

- **<u>Quantitative Approach:</u>**
  - **<u>Data Collection:</u>**
    - Subjects Identification (Location; measurements time; and participants).
    - Preliminarly data collection by using Zephyr Technology during training session.
    - Real construction site measurements by utilization Zephyr technology.
    - Weather Conditions Records (Weatherspark website based on "King Abdulaziz Air Base (Dhahran International Airport)" records).
    - Questionnaire.
  - **<u>Data Analysis:</u>**
    - Statistical Analysis such as T-Test and Grubbs' Test by using available software.
    - Calculating acceptable physiological bonds and heart rate zones (Buller & Karis (2007); and Lee and Migliaccio (2014)).
    - Results Interpretation.
    - Conclusion.

**Research Objectives**

- **<u>Research Objectives:</u>**
  - Providing a quantitative assessment for extreme weather conditions on construction workers in SA.
  - Identifying the difference in workers' behavior and response under same conditions.
  - Identifying the acceptable physiological bounds and heart rate zones.
  - Identifying whether it is suitable to adopt a practical working threshold for construction workers.

**Figure 3.1 Research Steps and Methodology.**

Required steps for conducting the proposed study started by selecting the general idea and putting general statement. Then, the research process moved to another stage by conducting a comprehensive literature review of the previous studies that were conducted with considering four different themes (Construction workers' safety in general; heat and humidity impacts; PSM technology and Zephyr$^{TM}$ technology; and construction safety in SA) in order to identify scientific gaps in these themes. After identifying the scientific gaps, problem statement and research questions were formulated. Then, a quantitative approach was selected as the research method. The following subsection discusses the selected research method.

### 3.3.1 Data Collection

This study is targeting normal construction workers, who are working in different construction sites in the Kingdom of Saudi Arabia. As most of construction workers come from other countries, this study considered different physical body dimensions and allocated tasks. Hot weather conditions are the main concern of this study, therefore, the time for conducting this study is during the hottest periods in the year. Based on the historical data, the hottest period in the year is between May and September, in which the hottest month is July with Average High Temperature (A.HT) (44°C) (see Figure 3.2). Working time is also restricted according to the Saudi regulations. From June 25 to September 15, outdoors tasks are not allowed from 12AM to 3PM, except for oil and gas sector, and necessary maintenance activities (Saudi Ministry of Labor Resolution. 2010).

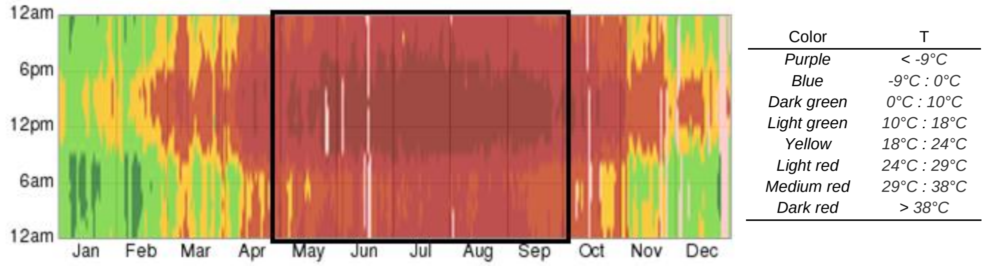


**Figure 3.2 Subjected period for collecting the data. (Source: weatherspark.com)**

#### 3.3.1.1 Used Tools and Technology

According to the literature, there are different tools and technologies that have been employed for monitoring physiological status of construction workers. In this study, Zephyr BioHarness™ 3 Technology was employed. This technology provides an effective tool for PSM with exceptional accuracy (Lee & Migliaccio, 2014; and Hailstone & Kilding, 2011). Zephyr technology has been proven and recommended to be used in construction industry (Lee & Migliaccio, 2014; Gatti, et al., 2011; Gatti, et al., 2014a; and Gatti, et al., 2014b). Furthermore, Zephyr BioHarness technology has also been successfully applied in different fields that are related to PSM (Table 2.4).

#### 3.3.1.2 Pilot Study

A pilot study was conducted to familiarize with the Zephyr technology tools and software. The pilot study was conducted using a group of volunteers from KFUPM students. The physiological status of the participants was monitored while they are playing a football match.

#### 3.3.1.3 Construction Site Measurement

Construction site measurements was held in in Dhahran, KSA after obtaining the approval from the site management. The participation was totally voluntary. The participants were divided into groups according to their job, nationality and day of recording. There was no any interruption to the participants' activities such that their physiological status were recorded simultaneously by using Zephyr technology.

#### 3.3.1.2 Type of Required Data

Three different types of data were collected in this study, which had been recorded data by Zephyr sensors. They are participants' related data; and weather conditions.

- ***Recorded data by Zephyr Sensors***

Zephyr sensors is able to provide a wide options of physiological status reports test the proposed hypothesis. Zephyr sensors could provide hourly records for different parameters and vital signs (OmniSense Live Help, 2014). In this study, only HR; BR; and oxygen uptake level were used in the analysis part.

These parameters can be displayed by using both Zephyr's applications OmniSense Live" and "OmniSense Analysis. OmniSense Live provides a live display for the mentioned parameters in different ways during the recording session. Such data allows the researcher to get a live data about the status of the workers and to monitor their conditions. In addition, it gives signs if any worker needs some rest and if his health conditions reach dangerous regions, as well as whether the workers performing any activity or not. Zephyr applications - OmniSense Live and OmniSense Analysis- have the ability to display the physiological status data of the participants in different ways. One of them is live data monitoring by using OmniSense Live which displays five subjects at the same time in five different BioGauge that are shown in the display screen. OmniSense Analysis also, represents a wild range of data reports that can be employed for different purposes. In this study, only three type (Hear Rate HR; Breathing Rate BR; and Maximum Oxygen Uptake Level $VO_{2_{max}}$)

of data were utilized in order to identify the acceptable HR and BR zones as well as acceptable HR physiological bounds.

- ***Data Related to the Participants***

At first the participant was asked the following questions:

- What is your name and what is your nationality?
- Have you ever been exposed to heat stroke in work?
- Do you suffer from any health problems?
- Do you suffer from any health problems in breathing?
- Do you suffer from any health problems in heart rate?
- Do you get any warning when degrees of temperature and humidity reach to dangerous levels?

Both in the pilot study and the construction site measurements, participants' height, weight, age and fitness level were measured. These data were entered to Bio OmniSense Live, which is a special software for BioHarness 3. The participants were asked to wear BioHarness Belt as it is shown in Figure 3.3. Based on their feeling and perception at the end of recording session they were asked to answer the following questions:

- Is wearing BioHarness Belt makes you performing your activities without any discomfort? (For site measurement perform your tasks?)
- Do you prefer that this belt was designed to be worn on wrist or shoulder? (For site measurement to be worn on wrist or helmet?)

**Figure 3.3 BioHarness Belt. (Zephyr PSM User Training Guid, 2011)**

- ***Data Related to Sit Environmental Conditions***

Weather conditions parameters (i.e. temperature and relative humidity) were retrieved from Weatherspark website based on the King Abdulaziz Air Base (Dhahran International Airport) records.

## 3.4 Data Analysis

This section addresses different techniques that were applied to analyze the recorded data. Most of these techniques are statistical tools and tests, such that all calculations were performed using the statistical software Minitab® 17.1.0 and Microsoft Excel 2013. Some HR and BR estimation equations were utilized to estimate the related variables. The Grubbs' test was applied for removing the outliers from the recorded data as a result of its tendency to follow normal distribution. In addition, the T-Test was employed to test the proposed hypothesis. The obtained results from the analysis were documented and organized in such way serving the proposed. The results of this study were compared with some previous studies in the same area.

## 3.5 Scope and Limitation

This section addresses the scope of the proposed study as well as the limitations. The proposed research and its results provide a valuable knowledge in the field of construction safety in Saudi Arabia and Arabian Gulf countries as well as construction industry in the world. The scope of this study is limited to Al-Dhahran, Eastern Provence, Saudi Arabia in which there were limited researches had been conducted in this field, and there was no application of the proposed technology before. In addition, the construction sector in Saudi Arabia involves multinational workers, who are working under special weather conditions which represents a special case.

The selection of the projects; participants; type of tasks; and recording dates and hours were determined according to the agreement of the relevant authorities. The number of participants in each recording session was limited due to the limited number of available sensors.

## 3.6 Conclusion

Construction workers' safety becomes a hot topic for researchers and construction organizations. Under this context, in-depth literature was conducted on heat and humidity impacts; PSM technology; and construction safety in SA. Based on the literature review, problem statement; research questions; and research objectives were identified. Investigating impacts of extreme weather conditions on construction workers' health and safety, using quantitative assessments, in Saudi Arabia has not been addressed. This study was conducted based on quantitative approach, such that real construction site measurements and observations took place during the hottest period in the year. In order to achieve the stated objectives, the recorded measurements and observations were analyzed by applying statistical analysis and tests.

# CHAPTER 4

# RESULTS OF ANALYSIS

## 4.1 Introduction

As described in the previous chapter, quantitative approach was used in this study by conducting site measurement. The recorded data of the site experiments was then analyzed to identify weather the workers under such weather conditions are performing their tasks under safe working conditions. This chapter also addresses the work activity intensity under extremely hot weather conditions. Moreover, the impacts of different factors on construction workers' physiological signs (HR and BR) are addressed by applying a statistical nonparametric test. The last part of this chapter includes regression models for construction workers' HR and BR by considering different working conditions.

## 4.2 Data Collection

Measurements were held in construction sites in Dhahran, KSA with the approval of the site managers. The participation was totally voluntary. The participants were divided into groups according to their job, nationality and day of recording. There was no interruption to the participants' activities such that their physiological status was recorded while they were performing their activities. The measurement was done by using Zephyr technology. The proposed study targets normal construction workers in Saudi Arabia, taking into account different physical body dimensions and allocated tasks. As hot weather condition is the main concern of this study, therefore, the target time for conducting this study was the hottest periods in 2015 and 2016. Based on the historical data the hottest period in the year are between May and September. The hottest month was July with A.HT (44°C) (see Figure 3.2). Working time is usually restricted according to the Saudi regulations. It is not legal for workers to perform tasks outdoors from 12AM to 3PM during this period (Saudi Ministry of Labor Resolution. 2010), with the exception of oil and gas sector and the necessary maintenance activities.

The purposes of the study were explained to the participants, in particular the nature of the Zephyr sensors and the type of measurements performed during conducting measurements. The participants performed their activities and tasks without any intervention from the observer, i.e. there is not any bias from the researcher in participants and activities selections.

The measurement was conducted in five different days, which were 24th, 25th and 27th of June 2015, then 18th and 28th of July 2016). The first three site measurements, which was in the summer of 2015, included 15 different participants who performed different activities. The four site measurements in 2016 included 20 participants. The participants have different nationalities as illustrated in Table 4.1.

**Table 4.1: Nationality of construction site experiments' participants.**

| Nationality | Measurements | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total | % |
| Pakistani | 2 | 1 | 1 | 1 | 1 | 1 | | 7 | 21% |
| Nepalese | 2 | 1 | 1 | 1 | 2 | 1 | | 8 | 24% |
| Indian | 1 | 3 | 1 | 1 | 1 | 2 | 4 | 13 | 39% |
| Philippine | - | - | 1 | - | - | | | 1 | 3% |
| Bangladesh | - | - | 1 | 1 | 1 | | | 3 | 9% |
| Egyptian | - | - | - | 1 | - | | | 1 | 3% |

The total percentage of the Indians, Nepalese and Pakistanis participants are 39%, 24% and 21%, respectively. Where the total proportion of the other participants is (Bangladesh, Philippines and Egyptian) 15%.

The first and second site measurements were recorded on $24^{th}$ and $25^{th}$ of Jun, 2015. In the first site measurements, the data collection was started at 09:50 A.M. and was completed at 02:37 P.M. The second site measurements started at 09:55 A.M. and ended at 02:16 P.M. There were few minutes' variations in the recording time as a result of the differences in the time of installing Zephyr belts from participant to another. The participants were allowed to take a rest from 11:45 A.M. to 1 P.M. for lunch and Al-Duhr prayer. There was one exception in the first measurement, as one of the participants had a permission to leave the site early. Therefore, the recorded time for this participant (02 hr: 57 min) was less than those of the other participants.

The first two site measurements were conducted in the same construction site, where a crew of one foreman and eleven labors performed their normal daily tasks. In this site, there were two main activities, outdoor and indoor activities. The outdoor activities included the installation of cooling tower for AC station structure at Al Dhahran - Saudi Arabia. The indoor activities included installing cooling tower's filters inside an open building, i.e. there was not an air-condition inside the building. Because the data collection was taking place in the month of Ramadan, two Muslims participants in the first measurement and one participant in the second measurement were fasting. This provided a special case for monitoring body response of workers performing their tasks while they were fasting. In the first three site measurements, different ages and body parameters of the participants were also recorded. Participants' ages were around 27 and 37, except two of them who were in the ages 42 and 51 (Table C1 of Appendix-C).

There were three different sessions included in the first and second measurements which were conducted in the same construction site. The first session started from the point of wearing the Zephyr belt, at the beginning of the measurement, and ended with the start of the second session – (resting period from 11:45 A.M. to 01:00 P.M.). Only outdoors activities under direct sunlight were performed in the first session. These activities included moving, transporting, handling, hammering and installing bolts as shown in Figure 4.1.

**Figure 4.1: Outdoors activities for the first and second measurements.**

During the resting period, the non-Muslim workers could take their lunch or drink water while taking their rest. The Muslim workers could not take their lunch or drink water because they were fasting. The third session included the indoors activities, where the workers had only simple tasks, such as handing and preparing AC station's filters, as shown in Figure 4.2.

**Figure 4.2: Indoors activities for the first and second experiments.**

The weather conditions for both the first and the second measurements seemed to be similar. The maximum and minimum temperature on the 24th and 25th of June, 2015 were 48/23 °C and 47/24 °C, respectively. The average maximum and minimum temperature on both dates were the same, which was 41 and 23 °C, respectively (see Table C2 in Appendix-C). Furthermore, there were not large differences between maximum and minimum humidity on both dates – only one degree was the difference – as shown in Figure 4.3 and Figure 4.4. Maximum and minimum humidity on 24th and 25th of Jun, 2015 were 19/7% and 22/8% respectively. The average humidity in both dates were the same, which was 20%.

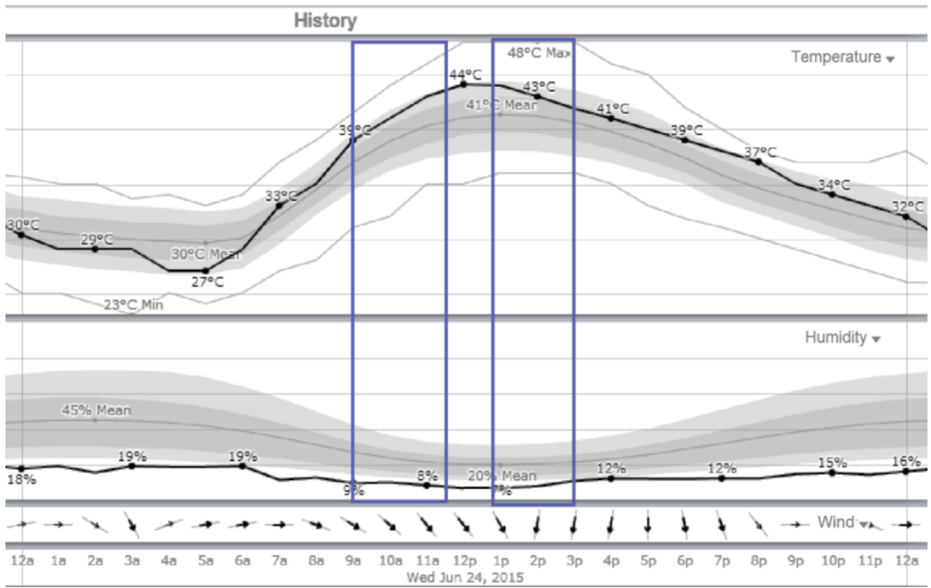


**Figure 4.3: Weather conditions for the first experiment (inner bands from 25 to 75 percentile and outer bands from 10 to 90 percentile). (Source: weatherspark.com)**

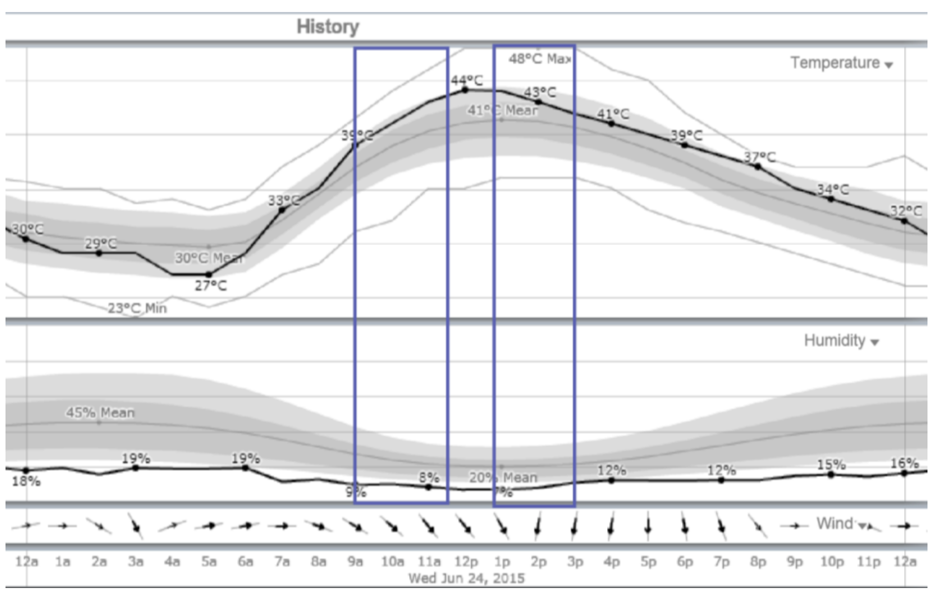


**Figure 4.4: Weather conditions of the second experiment. (Source: weatherspark.com)**

The third site measurements were conducted on 27$^{th}$ Jun, 2015. They started in the evening and continued to the following day (28th of Jun, 2015) – two days after the second site measurement – in a different construction site as shown in Figure 4.5.

**Figure 4.5: Outdoors activities for the third site measurement.**

The third site measurements included mainly activities of preparing the foundation for a parking building. Different sub-activities (formwork, excavation, shoveling, steel-bar preparing and concrete boring) were included in this part of the project. Five workers participated, who were monitored by Zephyr belts where four of them were performing formwork activity and the fifth one performing shoveling activity. Participants' ages were between 27 and 39 years old. The recording time in this measurement was during the night shift, from 9:58 P.M. (27 Jun 2015) and it continued for 04 hr.: 38 min with small differences in minutes from participants to another. There was a rest session started at 12:18 A.M. until 1 A.M ($28^{th}$ Jun, 2015). Participants physical status, ages and recording time are illustrated in Table C3, Appendix-C.

The weather conditions of the third site measurements were different than the previous site measurements. As it was conducted at the night shift, the humidity level was higher and the temperature lower compared to the day shift. Furthermore, the third measurement continued from the last hours of the 27th of June, 2015 to the early hours of the 28th of June, 2015. On those days (27th and 28th of Jun, 2015), the highest temperature was the same 47 °C and the maximum level of humidity were 60% and 40%, respectively. It was clear that the participants were suffering from the high level of humidity which reached to 40% as illustrated in Figure 4.6 (see Table C4, Appendix-C).

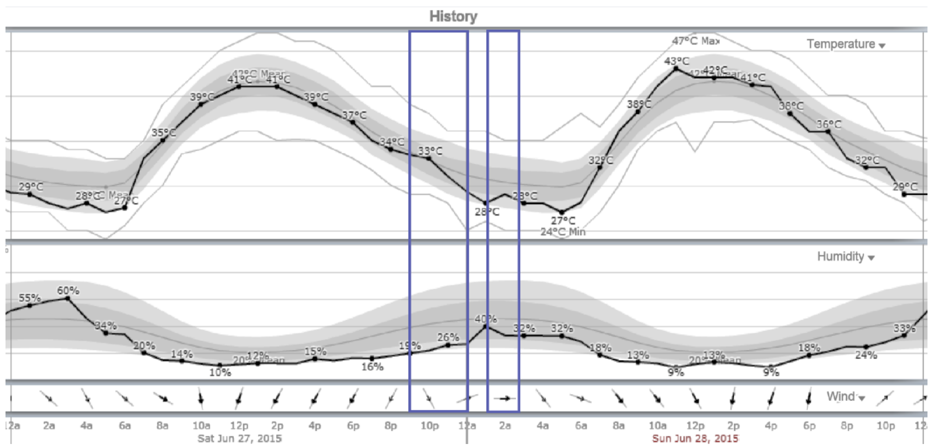


**Figure 4.6: Weather conditions of the third measurements. (Source: weatherspark.com)**

The other four site measurements were conducted on the 18th and 28th of July, 2016. These site measurements included 20 participants. Participates physical body parameters are summarized in Table C3, Appendix-C. The fourth site measurements were conducted in one of the parking-building project in Al-Dhahran, Saudi Arabia. The works included were mainly the steel work activities for the foundations as shown in Figure 4.7.

**Figure 4.7: Construction site of the fourth site measurements.**

The fifth construction site measurements included different activities such as steel work, carpenter, and for the first-time tower crane deriver as shown in Figure 4.8.

**Figure 4.8: Construction site of the fifth site measurements.**

The sixth and seventh site measurements were conducted in the same construction site that included steel work activities for columns as shown in Figure 4.9.

**Figure 4.9: Construction site of the sixth and seventh site measurements.**

The weather conditions of the last four site measurements were also considered as one of the hottest days in the year in Al-Dhahran, Saudi Arabia. The average temperature of the fourth, fifth, sixth and seventh construction site measurements were 37°C, 36°C, 37°C, and 41°C, respectively. The relative average humidity for these measurements were 40%, 37%, 40%, and 35%, respectively (see Table C6, Appendix-C).

Site measurements depend on the permission in determining recording time; weather conditions; and activities; however, site measurements covered different working sessions within morning and night shifts with taken in account weather conditions changes.

- ## Data Collection Protocol

The data collection was done using following steps:

1. The purpose of the measurements was explained to the site engineer to obtain a full corporation from the participants. In addition, it was explained that the measurements would not interrupt the workers in performing their activities and assigned tasks. Then, we asked five workers to participate in the measurements.
2. The participants in the site measurements were asked few questions about their health conditions. Seven question were proposed to be answered by the participants. Five of these questions were answered before wearing Zephyr sensors, which were:
   a) Have you ever been exposed to heat stroke in work?
   b) Do you suffer from any health problems?
   c) Do you suffer from any health problems in breathing?
   d) Do you suffer from any health problems in heart rate?
   e) Do you get any warning when the degree of temperature and humidity reach to dangerous levels?

   The other two questions, which are related to utilization of the sensors, were answered by the participants at the end of the recording session:

   f) Is wearing BioHarness Belt makes you perform your tasks without any discomfort?
   g) Do you prefer that this belt was designed to be worn on wrist or shoulder?
3. Workers physiological body parameters (age, height, and weight) were identified by asking them about their ages, and directly measure their height and weight.
4. The participants wore the BioHarness Belts on the recommended positions for the sensors as it is addressed in the Zephyr manual (see Figure 4.10).


**Figure 4.10: Samples of the participants with the utilized sensors.**

1. The Zephyr BioHarness technology provides two different types of software for monitoring the participants and providing warning signs in dangerous situations. This software was prepared by the observer. Participants information was entered to the system before starting the data recording. In addition, the connection between wireless ECHO gate and the sensors was checked by the observer. The available software included OmniSense Analysis and OmniSense Live. The OmniSense Live assists continuous monitoring purposes and provides warning signs for all participants in the same time as it is illustrated in Figure 4.11.

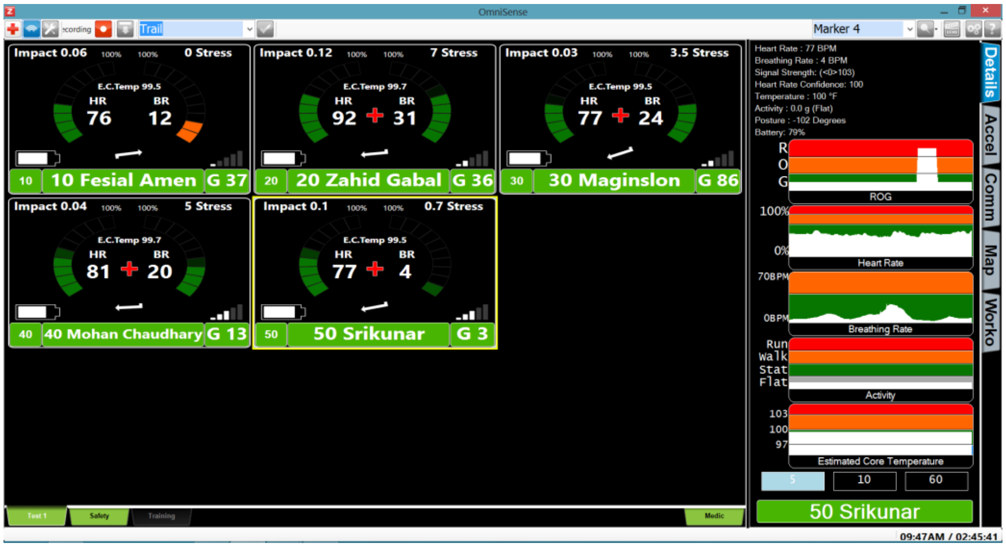

**Figure 4.11: OmniSense Live display screen for one of the recording sessions.**

The other software, OmniSense Analysis, provides a graphical presentation for the monitored workers and it supports analysis purposes as illustrated in Figure 4.12.

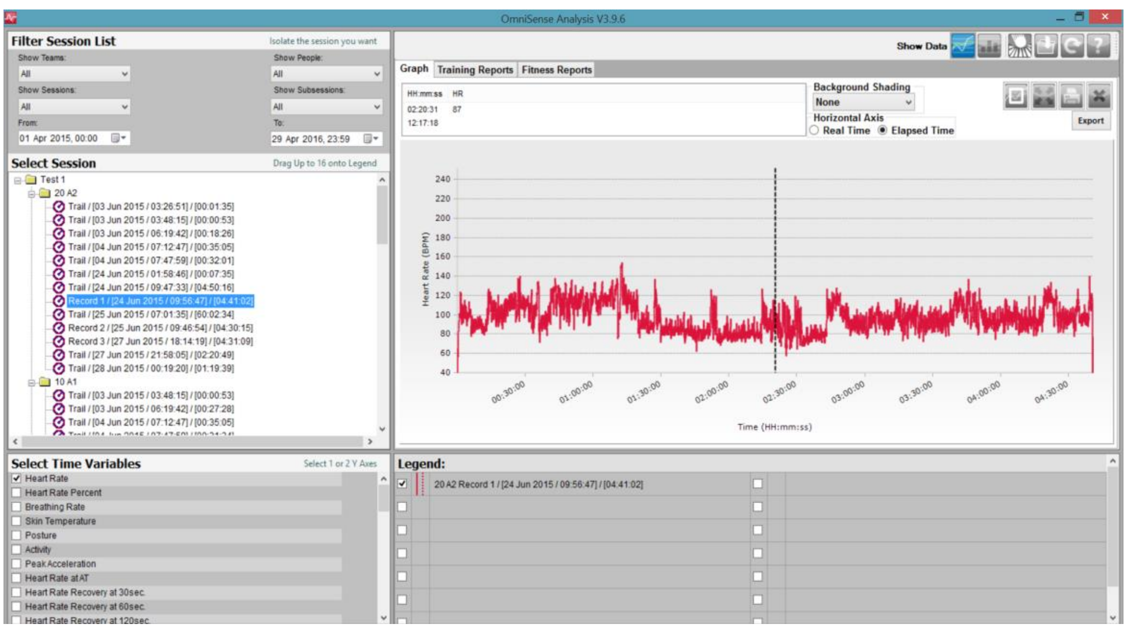

**Figure 4.12: OmniSense Analysis display screen for one of the recording sessions.**

## 4.3 Data Analysis

The site measurements included 35 participants having different physical parameters and ages as illustrated in Appendix-C (Table C1, Table C3, and Table C5). The participants were asked seven questions in order to identify whether they have any health problem in addition to assessing their opinions about how they feel when they wear Zephyr belts. The following figure summarizes their responses.

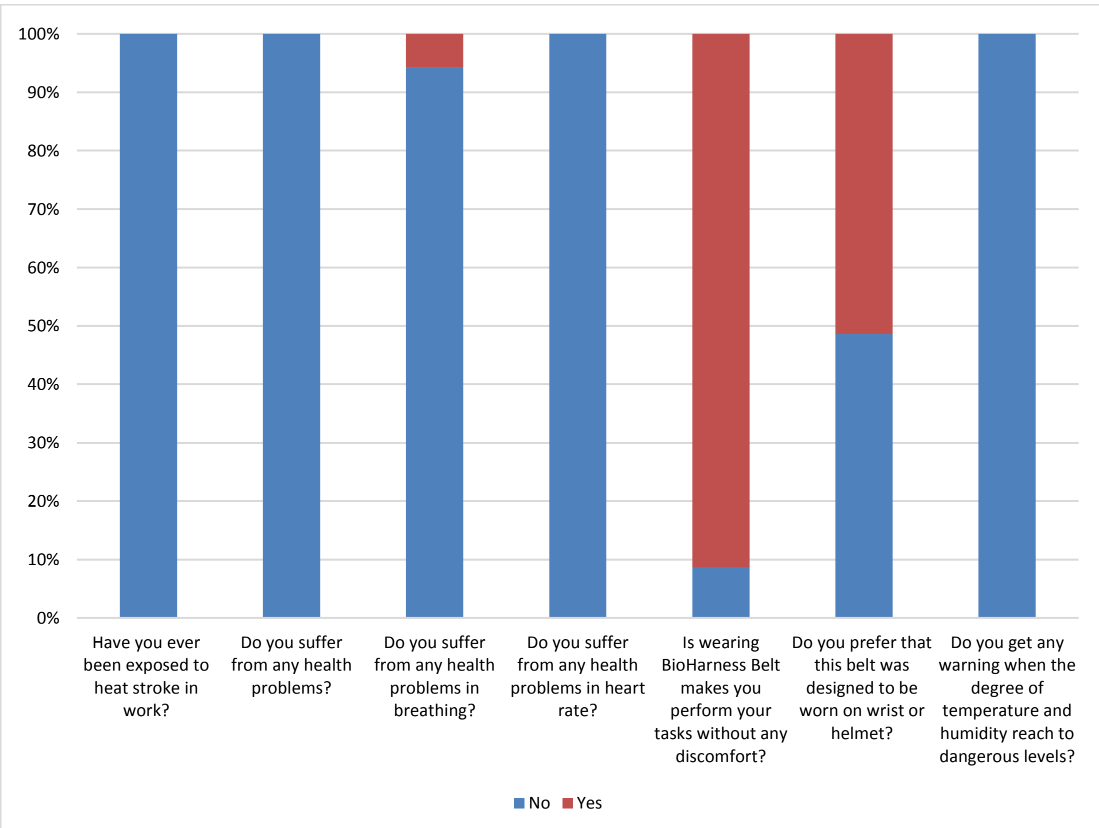


**Figure 4.13: Summary of participants' response in construction site measurement.**

Figure 4.13 illustrates that, the participants do not have any health problem regarding to heart. Only 6 percent of the workers had breathing diseases. 9 percent of the participants declared that wearing Zephyr belts creates discomfort during the work. 54 percent of the participants preferred Zephyr belts to be manufactured in such way that it possible to be worn in wrist or shoulder. One of the most noticeable results is that all of participants do not get any warning signs when the temperature and humidity reach to dangerous levels.

### 4.3.1 Acceptable HR physiological bounds and zones.

Acceptable HR and BR physiological bounds are the zones of human body in which the workers will not expose “to cardiovascular overload or overexertion” while they are performing their tasks. (Lee & Migliaccio, 2014). In this section, both HR ranges and zones are calculated in order to identify whether the construction workers under study were within the safe limits during the recording sessions.

- ***Two-tailed Grubbs’ Test***

At first, the recorded data had some fluctuations in the first one minute of the recorded HR and BR data (e.g. HR value reached to zero). This non-reasonable variability in HR and BR values during the first one minutes was resulted from the time that it takes to adjust Zephyr belts to be fitted with participants’ body in addition to the time that it takes to connect the sensors to the ECHO gate. Therefore, the data that was recorded in the first minute was eliminated before analyzing the data. Figure 4.14 represents a sample of the recorded data of subject 1 HR. For these reasons, a similar step was performed to eliminate the recorded data during the first minutes of each subject.

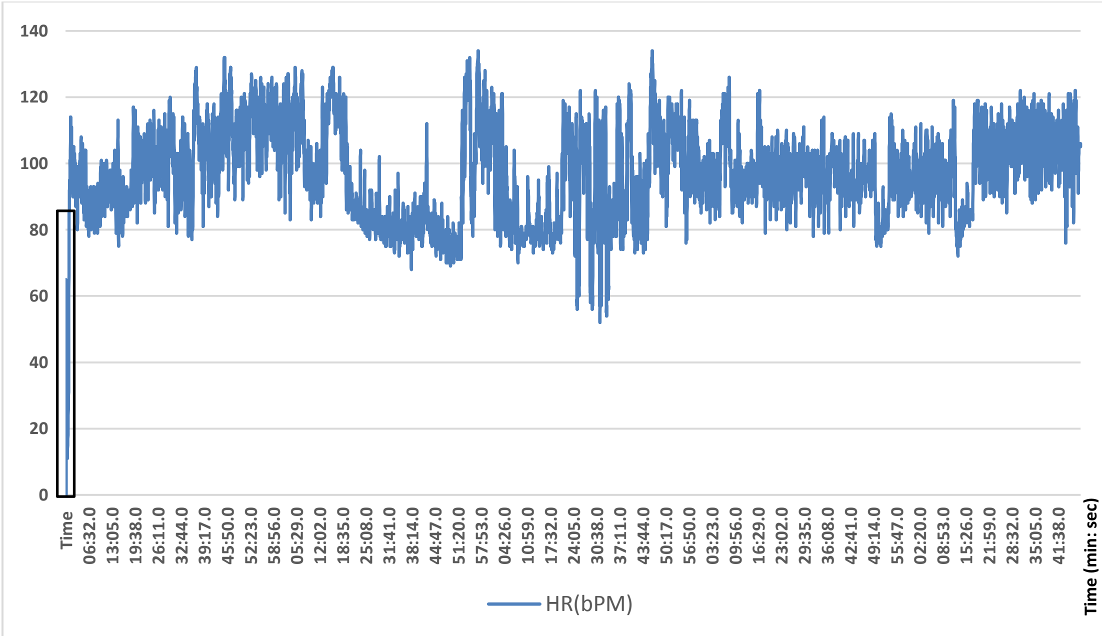


**Figure 4.14: Hourly HR and BR plot for subject 1 of the first site measurements.**

Grubbs' test is a statistical test that is applied for removing the outliers from a set of data that have the tendency to follow normal distribution (Grubbs & Beck, 1972). Normal human body heart and breathing rate distribution tend to normal distribution (Lee, Migliaccio, 2014). The results of detecting normality plot of the HR data show that, HR records tend to be normally distributed with some few outliers as it is shown in Figure 4.15 (see Appendix-D).

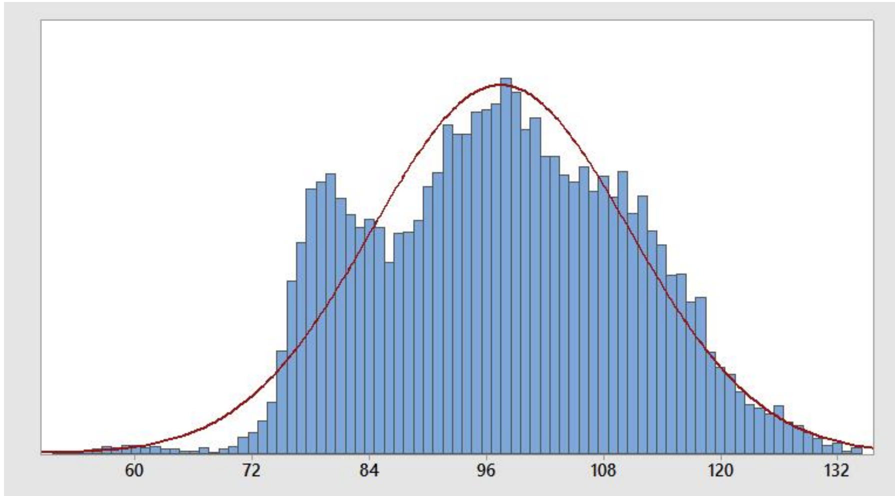


**Figure 4.15: Distribution plot for subject1 of the first site measurement.**

Therefore, Grubbs' test is applied to eliminate the outliers' points from the recorded data. Two-tailed ("smallest and largest value is an outlier") Grubbs' test is conducted by using Minitab software with significant level ($\alpha = 0.05$). Appendix-E includes Minitab's outputs of Two-tailed Grubbs' test for each subject. Minitab outputs for subject 2, session 2 HR of the first site measurements, reveal that there is not outlier in the recorded data because the P-value is less than the significant level ($\alpha = 0.05$). The previous steps applied for the remaining four subjects such that the first minute of the recorded data was eliminated at the first then outliers were eliminated. The results are of Two-tailed Grubbs' test for HR for each participant are summarized in Appendix-C (Table C7, Table C8, and Table C9).

In this study, different formulas were introduced that can be used to estimate different required variables in order to calculate acceptable HR physiological bounds and heart rate zones for the conducted measurements as it is explained in the following:

- ***Maximum heart rate ($HR_{max}$)***

In the literature, there are several valid formulas that can be used for estimating the maximum heart rate with considering different ages. This study adopted the most accurate formula (Wohlfart and Farazdaghi, (2003); and Lee and Migliaccio, (2014)) that had been applied successfully in construction safety applications.

$$HR_{max} = 203.7 \,/\, (\,1 + \exp(\,0.033 \times (\text{age} - 104.3)\,)\,) \qquad (4.1)$$

Where, $HR_{max}$ denotes to expected maximum HR.

- ***Target heart rate (THR)***

$$THR = \left((HR_{max} - HR_{min.\ rest}) \times intesity\%\right) + Avg.HR_{rest} \qquad (4.2)$$

- ***Heart rate reserve (HRR)***

$$HRR = Predicted\ HR_{max} - Avg.HR_{rest} \qquad (4.3)$$

- ***Body mass index (BMI)***

$$BMI = \frac{Weight\ (kg)}{(Height\ (m))^2} \qquad (4.4)$$

- ***Body fat percentage (%Fat)***

$$\%Fat = (1.20 \times BMI) + (0.23 \times Age) - (10.8 \times Gender) - 5.4 \qquad (4.5)$$

The statistical summary of the participants' records and the calculated values of BMI, Fat%, and predicted maximum HR are explained in more details in Appendix-A. The statistical summary of the recorded data is shown in Appendix-C (Table C10 and Table C11). Based on the results that is shown in Appendix-C (Table C10 and Table C11), there is an evidence that the construction workers in the morning shift had a higher average HR. The highest average HR values (116.33, 108.64, 105.3, 100.5, 103.64 BPM) are shown in the first site measurement in which the data recording was conducted at the morning shift. Moreover, the first and second subjects of the first site measurements in this study represent a special case because they were fasting during the measurements. Therefore, their records show a higher average HR than the others. The first subject of the second site measurements was also fasting but his HR records was not higher as much as the other fasting workers in the first site measurements. The applied equation for estimating maximum heart rate provides near values to the measured HR values such that the minimum ratio of measured over predicted HR was 58 during working sessions.

From the site measurements that was conducted on 2016, the maximum averages of HR (126.76, 120.86, and 118 BPM) were recorded in the morning working shifts in the fourth and the seventh site measurements similar to the construction site measurement of 2015. Acceptable HR physiological ranges.

$$HR_{min} = HR_{\min resting\ session} - \left(2 \times HR_{SD\ resting\ session}\right) \quad (4.6)$$

$$HR_{max} = HR_{\max working\ session} + (2 \times HR_{SD\ working\ session}) \quad (4.7)$$

- ***Acceptable HR physiological zones.***

Acceptable HR physiological zones is calculated at the desired activity intensity (60 - 70 %), which is suitable for human body to perform their activities without any risks on their health. Quantitative assessment for HR of the participants and identifying the acceptable HR physiological bounds for each participant provide a good indicator about activity intensity zone, and consequently the impact of weather conditions on the participants and their performance. The following formulas were applied to calculate the acceptable HR physiological zones:

$$HR_U = (Maximum\ Acceptable\ HR - \mathrm{HR}_{\min\, at\ rest})\times 0.70 + \mathrm{HR}_{\min\, at\ rest} \quad (4.8)$$

$$HR_L = (Maximum\ Acceptable\ HR - \mathrm{HR}_{\min\, at\ rest})\times 0.60 + \mathrm{HR}_{\min\, at\ rest} \quad (4.9)$$

Acceptable HR physiological bounds for different participants are summarized in Table C12, Appendix-C. Figure 4.16 and Figure 4.17 shows the acceptable HR range and bounds sein addition to the THR of the measurements of 2015 and 2016, respectively.

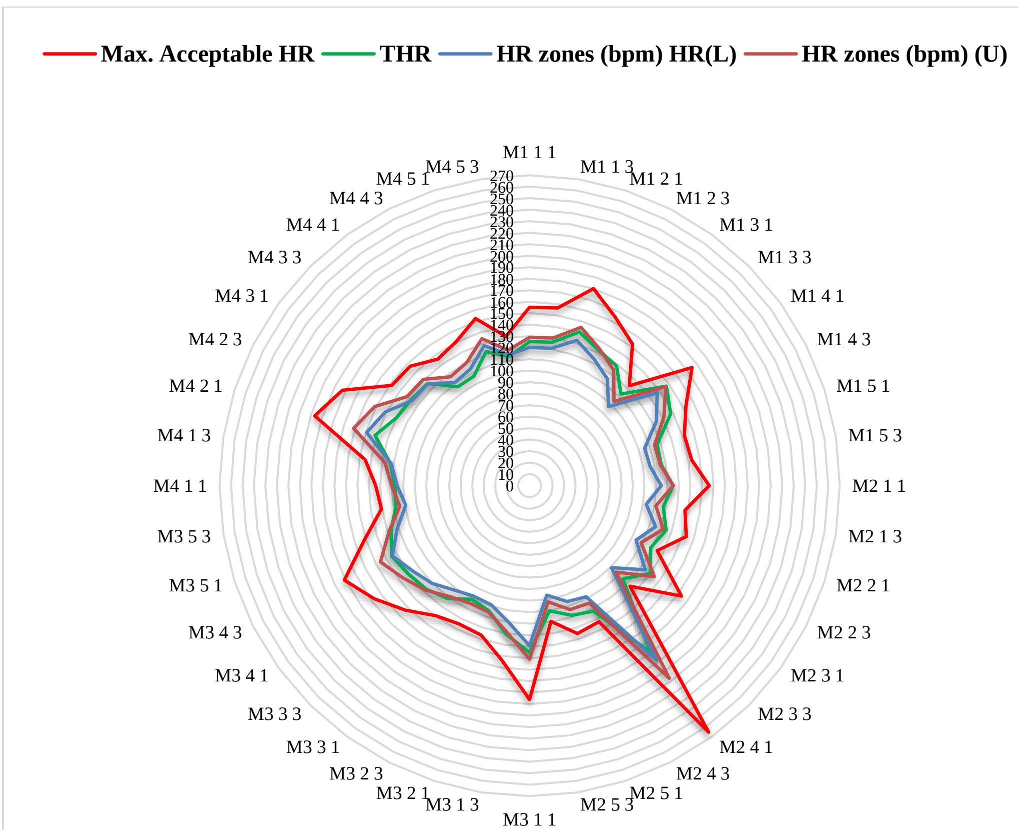


**Figure 4.16: Acceptable HR bounds and Zones for the measurements of 2015.**

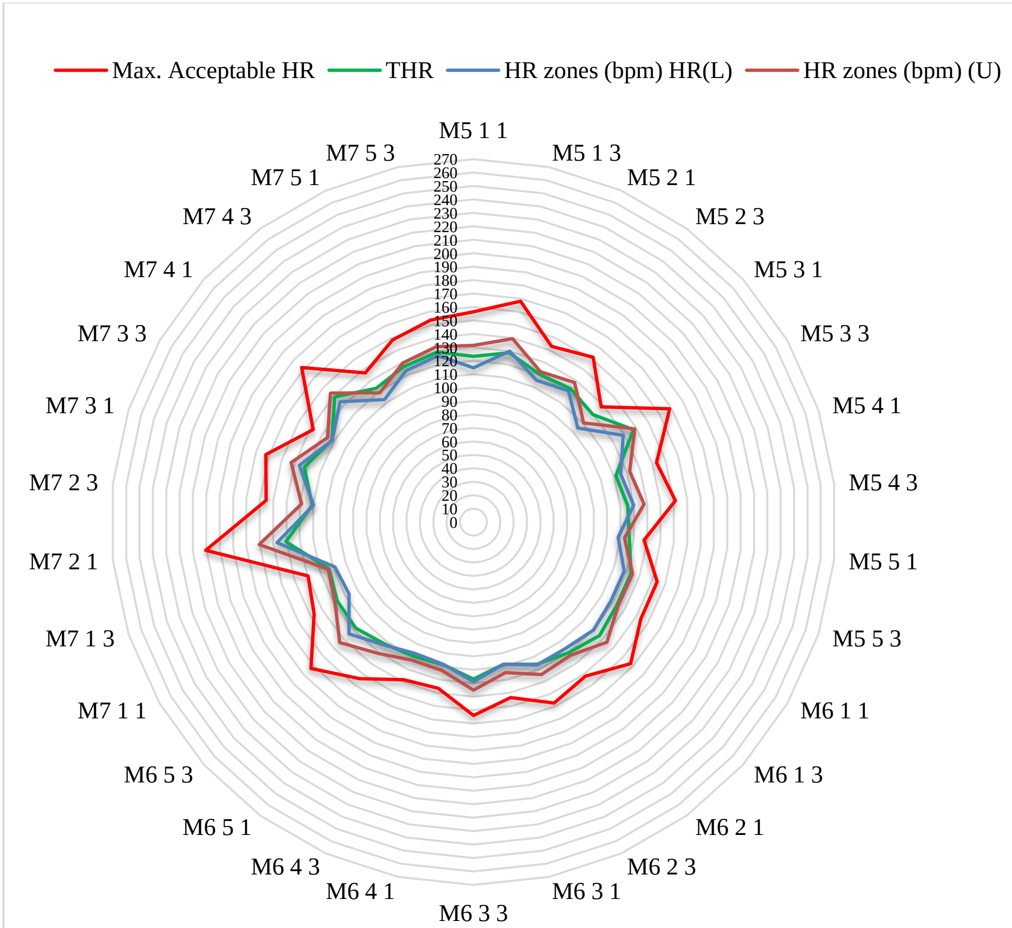


**Figure 4.17: Acceptable HR bounds and Zones for the measurements of 2016.**

The physiological parameters HR are used as an indicator for impacts of weather conditions on participants' health and safety. HR values that exceed the physiological thresholds indicate the participants were exposed to high risk and heat illnesses. Based on the calculated physiological thresholds, the percentage of records exceeding these thresholds can be identified as it is illustrated in Table C13 and Table C14, Appendix-C.

The results from the site measurements that were conducted in 2015 show that, all participants HR records exceeding the HR zones. This means that all participants were exposed to hazardous conditions during their working sessions. The highest percentage of exceeding the HR zones was recorded in the second and the fifth participants of the third site measurements, which were 3.161% and 4.583% of HR records exceeded the calculated HR zones, respectively. The results of the site measurements that were conducted in 2016 are summarized in Table C14.

### 4.3.2 Activity Intensity Level.

Desired activity level as it is addressed by Karvonen, M. J. (1957) and Lee & Migliaccio (2014) should be within 60-70% of the activity intensity percentage i.e. zone 2 in order to make the participants performing their tasks with high levels of productivity under light intensity. Five different zones are listed from the lowest to the highest intensity in Table A3, Appendix-A which will be used as an index for assessing activity intensity level.

Activity intensity can be calculated by different methods. The first method applied in this study was by using activity intensity zones index (see Figure 4.18) as an index to identify activity intensity level based on two variables $VO_{2_{max}}$ and METs. For identifying the zone that the participants were during their working session, it is required to calculate both $VO_{2_{max}}$ and METs of each participant as it is illustrated in Table A3, Appendix-A. Then, activity intensity zone was indented using Figure 4.18.

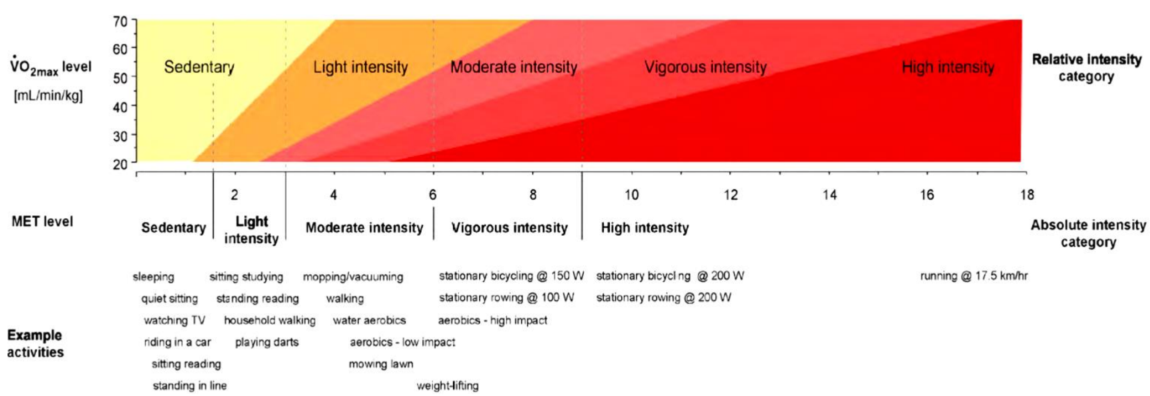


**Figure 4.18: Different activity intensity zones index (Norton, et al., 2010).**

- ***Maximum oxygen uptake ($VO_{2_{max}}$) level.***

The maximum oxygen uptake level ($VO_{2_{max}}$) could be calculated based on the result of maximum heart rate in the working session $HR_{max}$ divided by minimum heart rate during rest session $HR_{rest}$ as it is shown in Equation 4.10 (Uth, et al., 2004):

$$VO_{2_{max}} \approx 15.0\ (\frac{mL}{Kg \times min}) \times \frac{HR_{max}}{HR_{min.\ rest}} \qquad (4.10)$$

This study proposed to apply the same assumption of Broeder, et al. (1992), that calculates $VO_{2_{max}}$ by multiplying the ratio between the maximum heart rate in the working session $HR_{max}$ and the average heart rate during the rest session $Avg.HR_{rest}$ as it is shown in Equation 4.11:

$$VO_{2_{max}}^{*} \approx 15.0\ (\frac{mL}{Kg \times min}) \times \frac{HR_{max}}{Avg.HR_{rest}} \qquad (4.11)$$

- ***Metabolic equivalents (METs).***

$$\text{METs} = \frac{VO_{2_{max}}}{3.5\ mL.Kg^{-1}.min^{-1}} \qquad (4.12)$$

Appendix-C (Table C15 and Table C16) summarizes the calculated $VO_{2_{max}}$ and METs for each participant by applying the two equations (4.10 and 4.11) for the site measurements that were conducted both in 2015 and 2016.

By using activity intensity index (Figure 4.18), it is easy to identify the category of activities that the participants performed. For example, the calculated maximum oxygen uptake ($VO_{2_{max}}$) and metabolic equivalents (METs) for the first participant are 29.118 and 8.319, respectively. These two values were classified in the dark red region of Figure

4.18, which is the highest intensity zone. The decision of identifying work intensity category mainly depends on METs values as illustrated in Table 4.2.

**Table 4.2: Work intensity classification based on METs.**

| Zone Index | Intensity Category | Objective Measures | Description | Activity Intensity % |
|---|---|---|---|---|
| 1 | Sedentary | < 1.6 METs | Related to sitting based activities such as reading, watching, deriving car …etc., considered as a safe and conformable heart rate zone for workers (Norton, et al., 2010; Lee and Migliaccio, 2014). | ] 50:60%] |
| 2 | Light | 1.6 < 3 METs | Simple activities that do not increase breathing rate. Light activities and duties (Norton, et al., 2010) provide high productivity level (Lee & Migliaccio, 2014). | ] 60:70%] |
| 3 | Moderate | 3 < 6 METs | Hard normal work with achieving a good performance level and provide positive pressure (Lee & Migliaccio, 2014). | ] 70:80%] |
| 4 | Vigorous | 6 < 9 METs | Physical activities such as heavy lifting which cause difficulty in breathing and high levels of physiological stress (Norton, et al., 2010). Considered as unsafe zone (Lee & Migliaccio, 2014). | ] 80:90%] |
| 5 | High | ≥ 9 METs | The most hazardous zone in which the individuals cannot control their behaviors and they need a quick medical care to become in lower zones (Lee & Migliaccio, 2014). | ] 90:100%] |

Work intensity categories that is shown in Appendix-C (Table C15 and Table C16) summarizes the calculated $VO_{2_{max}}$ and METs for each participant by applying the two equations (4.10 and 4.11) for the site measurements that were conducted both in 2015 and 2016.

By using activity intensity index (Figure 4.18), it is easy to identify the category of activities that the participants performed. For example, the calculated maximum oxygen uptake ($VO_{2_{max}}$) and metabolic equivalents (METs) for the first participant are 29.118 and 8.319, respectively. These two values were classified in the dark red region of Figure

4.18, which is the highest intensity zone. The decision of identifying work intensity category mainly depends on METs values as illustrated in Table 4.2.

Table 4.2 are used to identify the intensity level of the assigned tasks for each participant in each site measurements. Task intensity level is identified based on the calculated METs values with considering two different methods (Equation 4.10 and Equation 4.11). These two methods were addressed in the literature as effective methods to identify activity intensity levels. The results of identifying activity intensity levels for the site measurements that were conducted in 2015 and 2016 were summarized in Appendix-C (Table C17 and Table C18). Three sessions were addressed in the data analysis where ten working sessions were included in each site measurement with considering indoors and outdoors activities and morning and night working shifts. The summary of activity intensity level identifying is show in Figure 4.19

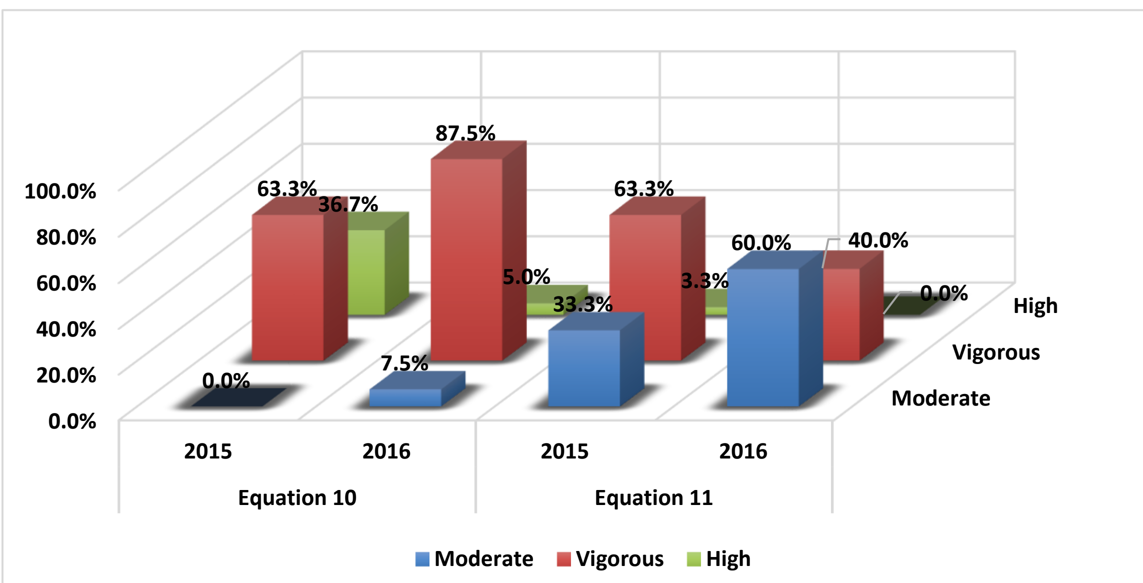


**Figure 4.19: Summary of activity intensity analysis for site measurement of 2015 and 2016.**

The results of identifying the actual and calculated activity zones for each participant in each measurement shows that:

1- The results of calculating activity intensity by using equation (4.10) denote to that, most of the working intensity are located within vigorous intensity zone for the site measurements of 2015. This zone also considered as a hazardous working zone (Lee & Migliaccio, 2014), where heavy activities may cause difficulty in breathing and high levels of physiological stress (Norton, et al., 2010). Some sessions included high intensity activities such as the first and third session for the second participants in the first measurements and the second participant of the second measurements. These participants were fasting during both sessions. Moreover, there were nine sessions in the 2015 site measurements that included high intensity activities. In the site measurements that were conducted in 2016, only two working sessions were classified in the highest activity intensity zones. In the 2016 measurements, the workers were allowed to self-pace during the working sessions, which is different from the site measurements that were conducted on 2015. Most of the working sessions in these measurements (2015 and 2016) are located within the vigorous intensity zones such that 35 of 40 sessions were vigorous intensity zones. Only three sessions were moderate intensity zones which is appropriate for the workers' health and safety to work under this conditions.
2- The proposed method for calculating activity intensity levels for the 2015 site measurements resulted in three different levels of work intensity, including moderate, vigorous and high intensity levels. Most of the 70 working sessions sessions were classified within the vigorous intensity which indicate unsafe

working conditions. One session was classified in the high intensity level, which was recorded in first session of the fourth participant in the second site measurements. In addition, nine sessions showed moderate working intensity levels which represents a good performance level and provide positive pressure for the assigned activities. On the other hand, most of the working sessions were moderate working intensity such that 24 out of 40 were moderate and the other sessions were vigorous intensity levels.

## 4.4 Factor Affecting Heart-Rate (HR) and Breathing-Rate (BR)

### 4.4.1 Physical Parameters

This section discusses the correlation between heart and breathing rates (HR/BR) of the participants and their physical body parameters such as height, weight and age. This step is important in order to identify the impact of such parameters on HR and BR. Kruskal-Wallis non-parametric test was applied with considering the significant level ($\alpha$) of 0.05 and the following null and alternative hypotheses:

$(H_0)_1$: There is no significant difference on the recorded HR as a result of different physical body parameter.

$(H_0)_2$: There is no significant difference on the recorded BR as a result of different physical body parameter.

$(H_1)_3$: There are significant differences on the recorded HR as a result of different physical body parameter.

$(H_1)_4$: There are significant differences on the recorded BR as a result of different physical body parameter.

The first body parameter is the age of the participants. In the 2015site measurements, the average age of the participants was 33 years, where the maximum and the minimum ages included in the measurements were 51 and 24, respectively. The average height of the participants was 66.799 inches and the maximum and the minimum height were 74.800 and 59.060 inches, respectively. The average weight of the participants was 162.555 Ibs, where the maximum and the minimum weight were 198.420 and 119.050 Ibs, respectively. The output of Kruskal-Wallis non-parametric test by using Minitab software are shown in Appendix-E. The following table summarizes the results of Kruskal-Wallis test for physical parameters impacts in the 2015 site measurements.

**Table 4.3: Results of Kruskal-Wallis test for physical parameters impacts for site measurements of 2015.**

| Factors | HR/BR | P-Value | Decision | | Max. Avg. Rank |
|---|---|---|---|---|---|
| Age | HR | 0 | <0.05 | Significant | Age (27) |
| | BR | 0 | <0.05 | Significant | Age (26) |
| Height | HR | 0 | <0.05 | Significant | Height (67.32) |
| | BR | 0 | <0.05 | Significant | Height (69.29) |
| Weight | HR | 0 | <0.05 | Significant | Weight (187.39) |
| | BR | 0 | <0.05 | Significant | Weight (180.78) |

There are significant differences within the recorded HR and BR values as a result of the differences in the ages of the participants. In addition, the highest average ranks in the recorded HR are identified within 27, 36, and 37 years old where the highest average ranks in the recorded BR are identified within 24, 26, and 39 years old. There is a significant difference within the recorded HR and BR values as a result of the differences in heights of the participants. The highest average ranks in the recorded HR are identified within the height of 59.06, 67.32, and 68.5 inches where the highest average ranks in the recorded BR are identified within the height 63.78, 66.14, and 69.29 inches. A significant difference is identified within the recorded HR and BR values as a result of the differences in participants' weights. In addition, the highest average ranks in the recorded HR are identified within the weight of 119.05, 154.32, and 187.39 Ibs where the highest average ranks in the recorded BR are identified within the weight 180.78, 141.1, and 136.69 Ibs.

In the 2016 site measurements, the average age of the participants was 34 years, where the maximum and the minimum were 46 and 24, respectively. The average height of the participants was 67.521 inches and the maximum and the minimum height were 74.800 and 61.02 inches, respectively. The measurements included 20 participants with the average weight of 170.417 Ibs, where the maximum and the minimum weight were 196.210 and 121.250 Ibs, respectively. The output of Kruskal-Wallis non-parametric test by using Minitab software are shown in Appendix-F. The results of the Kruskal-Wallis non-parametric test are summarized in the following table:

**Table 4.4: Results of Kruskal-Wallis test for physical parameters impacts for site measurements of 2016.**

| Factors | HR/BR | P-Value | Decision | | Max. Avg. Rank |
|---|---|---|---|---|---|
| Age | HR | 0 | <0.05 | Significant | Age (36) |
| | BR | 0 | <0.05 | Significant | Age (46) |
| Height | HR | 0 | <0.05 | Significant | Height (69.69) |
| | BR | 0 | <0.05 | Significant | Height (69.69) |
| 1. Weight | HR | 0 | <0.05 | Significant | Weight (165.35) |
| | BR | 0 | <0.05 | Significant | Weight (143.30) |
| | BR | 0 | <0.05 | Significant | Weight (143.30) |

The results of the applied test show that, all the physical parameters (age, height, and weight) of the participated workers have significant impacts on both HR and BR. The maximum average ranks (MARs) of the recorded HR and BR are identified within the age of 36 and 46 years old and within the height 69.96 inches. Moreover, the MARs of the recorded HR and BR are identified within the weight of 165.35 and 143.30 Ibs, respectively. The results of Kruskal-Wallis non-parametric test for the site measurement in both 2015 and 2016 support the argument that the ability of workers to work safely under the extremely hot and humid weather conditions is influenced by their physical body factors including age, height, and weight (Bates & Miller, 2002).

### 4.4.2 Degree of Temperature and Humidity

Physiological signs, such as HR and BR, are good indications for the impact of extremely hot and humid weather conditions on human body. For this study, the hourly data on temperature and humidity was provided by Weatherspark website, which was based on King Abdulaziz Air-Base (Dhahran International Airport). The data of HR and BR were summarized in the average of five-minutes interval. The temperature and humidity data were interpolated, using Eqquation 4.13, in order to calculate the temperature and humidity in five-minute interval.

$$y = y_0 + (y_1 - y_0)\times\frac{x-x_0}{x_1-x_0} \tag{4.13}$$

$y$ denotes the estimated temperature/humidity level at the $x^{th}$ minutes, which is located between two points $(x_0, y_0)$ and $(x_1, y_1)$. Table C19, Appendix-C summarized the data of

HR and BR of the first participant in the first site measurements in relation to the temperature and humidity.

The Kruskal-Wallis non-parametric test was then applied to identify the influence of temperature and humidity on the HR and BR. Appendix-E summarized the results of this test. The results of the 2015 site measurements show a significant level ($\alpha$) of less than 0.05, which indicate that there is a significant impact of temperature and humidity on construction workers' HR and BR. Therefore, the null hypotheses are rejected. For the 2016 measurements, there is an evidence that the temperature and humidity have significant impact on construction workers HR. Similarly, construction workers' BR was also significantly affected by the temperature. However, relative humidity did not have a significant impact on workers' BR.

### 4.4.3 Assigned Activity

The site measurements included different working activities. In the 2015 measurements, the activities were classified into two main categories which are indoors and indoors activates. These two categories involved activities such as: steel structure preparation including lifting, transportation, handling and moving in the morning shifts; and formwork and shoveling activates in the night shifts. Moreover, these categories include indoors activities of preparing AC-station filters. In order to identify whether there is a significant difference within the recorded HR and BR as a result of different working activities, the following hypotheses were tested by using the Kruskal-Wallis nonparametric test. The proposed null hypotheses are:

$(H_0)_1$: There is no significant difference on the recorded HR as a result of different working activities (Outdoors and indoors activities).

$(H_0)_2$: There is no significant difference on the recorded BR as a result of different working activities (Outdoors and indoors activities).

$(H_0)_3$: There is no significant difference on the recorded HR as a result of different working activities (assigned tasks including structure installation; filter preparation; formwork; shoveling activities; and resting).

$(H_0)_4$: There is no significant difference on the recorded BR as a result of different working activities (assigned tasks including structure installation; filter preparation; formwork; shoveling activities; and resting).

Therefore, the alternative hypotheses are:

$(H_1)_1$: There is significant difference on the recorded HR as a result of different working activities (Outdoors and indoors activities).

$(H_1)_2$: There is significant difference on the recorded BR as a result of different working activities (Outdoors and indoors activities).

$(H_1)_3$: There is significant difference on the recorded HR as a result of different working activities (assigned tasks including structure installation; filter preparation; formwork; shoveling activities; and resting).

$(H_1)_4$: There is significant difference on the recorded BR as a result of different working activities (assigned tasks including structure installation; filter preparation; formwork; shoveling activities; and resting).

The P-values of the Kruskal-Wallis test are lower than the significant level ($\alpha = 0.05$) (see Appendix-E.1-part k, and l). This indicates that there are significant differences on the recorded HR and BR due to the different activities (indoors and outdoors activities).

The average ranks of the HR and BR for the outdoors activates are 437.5 and 459.3, respectively, which are significantly higher than the average ranks for HR and BR for indoor activities (363.1 & 339.9, respectively). Based on these results, it can be interpreted that the outdoors activities have higher impact on the participants' HR and BR.

The results of Kruskal-Wallis test shown in Appendix-C, 1-part m and n represent the output of Kruskal-Wallis Test that is conducted by using Minitab software with considering different classification for the assigned activates:

The Kruskal-Wallis test results also show a significant impact of the second classification of the assigned activates on HR and BR. The recorded data of participants HR and BR were grouped based on the assigned activities rather than indoor-outdoor activities. The activities include: structure installation, filter preparation, formwork, shoveling and resting. The P-values of the Kruskal-Wallis test are lower than the significant level ($\alpha = 0.05$). This indicates that there are significant differences on the recorded HR and BR due to the different working activities (assigned tasks including structure installation; filter preparation; formwork; shoveling activities; and resting). For the impact on HR, the structure installation activities have the highest average rank (514.4), followed by the filter preparation (400.8), which represent activities performed in the morning shifts. Structure installation activates were conducted outdoors and filter preparation was taken place indoors. The results for BR show that shoveling and formwork activities have the highest average rank of 563 and 465.2, respectively. These two activates were taken place during the night working shifts where the relative humidity was higher than the morning shifts.

In the 2016 site measurements, only outdoors activities were included in the measurements. The tasks included were steel work such as steel fixer and carpenter, in addition to tower crane and loader drivers. The hypothesis of these measurements is:

$(H_0)_5$: There is no significant difference on the recorded HR as a result of different working activities (assigned tasks including steel fixer, carpenter, tower crane and loader drivers, and resting activities).

$(H_0)_6$: There is no significant difference on the recorded BR as a result of different working activity (assigned tasks including steel fixer, carpenter, tower crane and loader derivers, and resting activities).

The P-values of the Kruskal-Wallis test are lower than the significant level ($\alpha = 0.05$). This indicates that there are significant differences on the recorded HR and BR due to the different assigned tasks. In term of HR, loader driver had the highest rank of the HR average of 401.1, followed by the steel work activities with the average HR of 291.6. In the measurement of 2016, Loader deriver had the highest rank of the HR and the carpenter had the highest rank of BR. The lowest HR average rank is identified in the Carpenter records and for the lowest BR average rank Tower Crane Driver.

### 4.4.4 Working Shifts

The study also addressed the impact of different working shifts (morning and night) on HR and BR of the participants. The morning working shifts during the hottest session in Saudi Arabia starts on 5:00 AM up to 11 AM. The night working shifts include two different periods. The first period from 3:00 PM up to 5:00 PM and the other period from 5:00 PM to 12:00 AM. Both the 2015 and 2016 site measurements involved morning and night working shifts. The proposed null hypothesis to investigate whether different working shifts have a significant impact on construction workers' HR and BR is:

$(H_0)_7$: There is not significant difference on the recorded HR as a result of different working shifts (morning and night shifts).

The results of the Kruskal-Wallis Test are summarized in Table 4.5:

**Table 4.5: Kruskal-Wallis Test: BR versus Tasks of the construction site measurements of 2015 and 2016.**

| Factors | HR/BR | P-Value | Decision | |
|---|---|---|---|---|
| Site measurements of 2015 | | | | |
| Morning and Night working shifts | HR | 0 | <0.05 | Significant |
| | BR | 0 | <0.05 | Significant |
| Site measurements of 2016 | | | | |
| Morning and Night working shifts | HR | 0.520 | >0.05 | Insignificant |
| | BR | 0.509 | >0.05 | Insignificant |

The results of the Kruskal-Wallis test for the 2015 measurements show that, different working shifts have significant impact on the construction workers HR and BR. The recorded HR in morning shifts have higher average rank than the night shifts and the recorded BR in night shifts have higher average rank than the morning shifts.

The results of site measurements of 2016 show that, the working shifts have not a significant impact on construction workers HR and BR because most of the night shifts of the site measurements of 2016 were recorded between the period 3:00 PM to 5:00 PM in which no large differences within the recorded degree of temperature and relative humidity. On the other hand, most of the night working shifts in site measurements of 2015 were conducted within the period 5:00 PM to 12:00 mid night. However, similar results were noticed regarding the average rank of HR and BR in morning and night shifts such that the highest average rank of the HR were identified in morning shifts and the highest average rank of BR were identified in night shifts.

### 4.4.5 Workers' Status

The 2015 site measurements included special condition, in the case of fasting construction workers because the measurements were taken place in fasting month of Ramadan. During the first and second site measurements, there were three participants who were fasting. Those fasting participants performed their tasks normally as the other participants. The following hypothesis was tested by using Kruskal-Wallis nonparametric test with considering significant level ($\alpha = 0.05$). The proposed null hypothesis is:

($H_0$): There is no significant differences on the recorded HR and BR as a result of construction workers' status (whether they are fasting or not).

The alternative hypothesis is:

($H_1$): There are significant differences on the recorded HR and BR as a result of construction workers' status (whether they are fasting or not).

For both HR and B, the calculated P-values of the Kruskal-Wallis test are lower than the significant level ($\alpha = 0.05$). It was a clear evidence that different workers' status has significant impacts on participants' HR and BR. The workers who were fasting show higher average HR rank than those who were not fasting. The fasting workers' average HR rank is 435.2 and normal workers average HR rank 392.5. On the other hand, fasting workers have lower average BR rank than the normal workers.

## 4.5 Regression Model

In this section, general linear regression models are proposed for estimating construction workers' HR and BR based on different scenarios for working and environment conditions. Different combinations of the proposed scenarios for construction workers are suggested with considering three main factors, which are: working shift (morning and night working shifts); assigned tasks; and workers' status. Table 4.6 summarizes the regression models for the proposed scenarios with considering recorded HR data:

**Table 4.6: Regression models for construction workers' HR.**

| Working Shift | Activity | Fasting | Normal |
|---|---|---|---|
| Morning | Structure installation | HR = 37.9 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 41.0 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Resting | HR = 29.6 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 32.7 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Filter preparation | HR = 29.1 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 32.2 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Formwork | HR = 34.0 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 37.0 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Shoveling | HR = 26.7 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 29.8 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |

**Table 4.6: Regression models for construction workers' HR.**

| Working Shift | Activity | Fasting | Normal |
|---|---|---|---|
| Night | Structure installation | HR = 47.4 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 50.5 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Resting | HR = 39.1 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 42.2 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Filter preparation | HR = 38.6 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 41.7 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Formwork | HR = 43.4 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 46.5 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |
| | Shoveling | HR = 36.2 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight | HR = 39.3 + 0.626 Degree of Temperature - 0.275 Humidity - 0.2086 Age + 0.479 Height + 0.0686 Weight |

The same approach is applied for proposing general linear regression models for construction workers' BR, considering the same working and environment conditions. Table 4.7 summarizes the regression models for construction workers' BR.

**Table 4.7: Regression models for construction workers' BR.**

| Working Shift | Activity | Fasting | Normal |
|---|---|---|---|
| Morning | Structure installation | BR = 7.5 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 9.0 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Resting | BR = 6.9 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 8.4 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Filter preparation | BR = 4.3 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 5.8 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Formwork | BR = 7.8 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 9.3 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Shoveling | BR = 9.9 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 11.4 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |

**Table 4.7: Regression models for construction workers' BR.**

| Working Shift | Activity | Fasting | Normal |
|---|---|---|---|
| Night | Structure installation | BR = 5.2 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 6.7 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Resting | BR = 4.6 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 6.1 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Filter preparation | BR = 2.0 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 3.5 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Formwork | BR = 5.5 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 7.0 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |
| | Shoveling | BR = 7.6 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight | BR = 9.1 + 0.172 Degree of Temperature + 0.219 Humidity - 0.0648 Age + 0.0288 Height + 0.0069 Weight |

There are several models that are applied for HR and BR estimation such as equation (4.1) which mainly depends on age to estimate the HR. In the literature, this equation was applied for estimating the HR of construction workers (Wohlfart and Farazdaghi, 2003; and Lee and Migliaccio, 2014). However, it does not give good estimations with considering different tasks and working environments including extremely hot and humid weather conditions (see Appendix-C, Table C10 and Table C11). Therefore, it is essential to provide estimation models that take in account type of tasks, degree of temperature, relative humidity, age, workers' weight and height, and their status. The proposed research attempts to provide such models based on the available sample size. This regression models also describe the relation between the addressed factors and construction workers' HR and BR.

## 4.6 Discussion

This research addressed the impacts of extremely hot and humid weather conditions on construction workers' health and safety in Saudi Arabia with considering different factors such as physical parameters of the workers, indoors/outdoors activities, assigned tasks, morning/night working shifts, and workers' status (fasting or not). Regarding the first objective of the proposed research, this research provides a quantitative assessment for the impact of extremely hot and humid weather conditions in Saudi Arabi. The quantitative assessment depends on the physiological responses (HR and BR) measured by applying PSM technology.

Different workers have different responses and behaviors under the same working conditions. This is because workers' physiological responses are significantly influence by different physical parameters. In addition, degree of temperature and humidity have different impacts on workers under the same conditions. For instance, under the same conditions there were some of the workers exposed to hazardous and some of them did not. Moreover, the construction workers have different physiological responses in different working shifts and with different activities and assigned tasks. Fasting workers' physiological responses show that they are exposed to hazardous working conditions more than the normal workers. Therefore, as the workers' status (fasting/not) is vary as their physiological responses differ.

Work scheduling and tasks allocation are playing a major role in reducing the impacts of extremely hot and humid weather conditions such that most of the hazardous working sessions were identified within morning shifts. In addition, different tasks have different impacts under the same conditions including weather the assigned tasks are performed indoors or outdoors as well as type of tasks (see chapter 4, section 4.4.3).

This research identified the acceptable HR bounds and zones for the cases under study with considering the extremely hot weather conditions in Saudi Arabia. In each working session, each construction worker has a maximum limit for the HR bounds (see Table C12 Appendix-C). As illustrated in Figure 4.16 and Figure 4.17, if any worker exceeded these limits, his status will reach to the most dangerous level. Therefore, it is recommended to keep the workers.

Acceptable HR zones depends on the intensity level of the assigned activities and tasks. As much the recorded HR exceeded the limit as much the workers exposing to dangerous working conditions and work intensity level reach to more hazardous regions. Figure 4.16 and Figure 4.17 illustrates the acceptable HR zones for each worker in each working session. All recorded sessions of the participated workers exceeded the acceptable HR zones which means they exposed to hazardous working conditions and the work activity intensity is higher than the acceptable level (moderate intensity). Therefore, these workers need quick and direct intervention through schedule resting periods and let them to be hydrated sufficiently in addition to working with self-pace or even medical intervention (Bates & Schneider, 2008; Rowlinson, et al., 2014). By applying such procedures for prevention, the safety levels of construction workers are improved as it was shown in the results of the site measurements of 2016, where the participated workers were allowed to work with self-pace and they hydrated sufficiently. Therefore, their results were much better than the site measurements of 2016 (see Appendix-C, Table C14).

Three different intensity levels were identified within the conducted measurements including moderate, vigorous and high intensity zones. Both vigorous and high activity intensity zones are considered as a hazardous working zone (Lee & Migliaccio, 2014) at which heavy activities are included which may cause difficulty in breathing and high levels of physiological stress (Norton, et al., 2010). However, moderate considered appropriate working zone for construction workers (Norton, et al., 2010; Lee & Migliaccio, 2014) as illustrated in Figure 4.19.

There is a clear evidence that construction workers' behaviors and responses are significantly influenced by physical parameters, workers' status, different working activity, assigned tasks, and working shift. Based on that, adopting fixed limits and thresholds is not recommended in very/extremely hot regions such as the case in Saudi Arabia. Therefore, the continuous monitoring system provide a reliable and valid tool for construction workers' health and safety and provide proactive indications for their conditions during working sessions. Moreover, different workers have different working thresholds based under extremely hot weather conditions. For example, in fourth site measurements, participants number 1 and number 4 were performing similar activities (Steel work activity) under same working conditions. however, the first participant HR records exceeded the acceptable HR zones where the fourth participant HR records did not. This means that, the first participant was exposed to hazardous working conditions and he needed a rest to recover from this conditions. Therefore, adopting fixed thresholds is inappropriate and does not considered the differences in the workers' responses and behaviors under the same working conditions (the same conclusion of Bates & Schneider, (2008) study). It is highly recommended to adopt practical working thresholds for the construction workers who are exposing to extremely hot weather conditions (the same conclusion of McDonald, et al., (2008) and Kjellstrom, et al., (2009) studies). Under the extremely hot weather conditions, adopting practical working thresholds helps in identifying whether each worker in the construction site are under safe working conditions or there is a need for apply one of the one of the preventive actions. For instance, it is clearly noted that the percentage of exceeding the HR zones in the measurements of 2016 much lesser that 2015 (see Appendix-C, Table C14). This is because the workers were allowed to work with self-pace and they hydrated sufficiently.

## 4.7 Summary

In this chapter, the proposed approaches and methods for analyzing the recorded data of the participants in seven different construction site measurements. The first stage of the analysis included calculating acceptable HR ranges and zones for the recorded HR data with considering working conditions and weather conditions (degree of temperature and humidity). The next stage of the analysis part was directed to identify intensity level of the assigned tasks under such weather conditions. The activity intensity zones were used as an indicator for the safety conditions of the monitored construction workers. The following parts of the data analysis included identifying the relationship between the recorded HR and BR with different factors such as physical body parameters; degree of temperature and humidity; assigned activities; and workers' status. Finally, this chapter proposed regression models for construction workers' HR and BR with proposing different scenarios for working conditions.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the main findings of the study. Following that, the conclusions and recommendations are presented. The recommendations include those for the construction industry to improve construction workers' health and safety with considering extremely hot and humid weather conditions, and some key points for future researches in this area.

## 5.1 Summary of The Research

This research addressed the impacts of extremely hot and humid weather conditions on construction workers' health and safety in Saudi Arabia. The main aim of this research is to provide a quantitative assessment of such working conditions in workers' health and safety by conducting real construction site measurements. This research answers three main questions including identifying the difference in workers' behaviors and responses under the same conditions; identifying the acceptable physiological bounds and heart rate zones for the workers; clarifying whether it is suitable to adopt practical working thresholds for workers.

This research includes five chapters. Chapter one introduces an introduction about the study including research problem, objectives, approach, and the significant. An in-depth literature review about construction workers' health and safety, application of PSM technology is addressed in chapter two. Chapter three descries the quantitative approach followed to acquire research objectives and answer the proposed questions. The conducted measurements, data collection and analysis is descried in chapter four with including a discussion for the analysis results.

The applied approach includes conducting seven real site measurements by using PSM technology with including 35 different construction workers in Saudi Arabia.

Construction workers' physiological responses are significantly influence by different physical parameters, degree of temperature and humidity, working shifts and assigned tasks and activities. Therefore, different workers have different responses and behaviors under the same working conditions.

The acceptable HR bounds and zones for each worker in each working session is identified by utilizing the HR records. The results of HR bounds and zones indicate to the worker who expose to hazardous working conditions and who not. In addition, the intensity levels of the assigned gives a scale for how far the workers are exposed to hazardous working conditions.

The results of the analysis clarify that, adopting fixed limits and thresholds is inappropriate to construction workers under extreme hot and humid weather conditions. In addition, the continuous monitoring system provides proactive indications for workers' health and safety conditions during working sessions. Under the extremely hot weather conditions, adopting practical working thresholds considered the variation in workers responses and identify whether the workers are under safe working conditions they need for apply preventive actions.

## 5.2 Conclusions

Numerous studies have addressed the impact of weather conditions on construction workers' health and safety as well as productivity. However, most of them failed to identify the impacts of extremely hot and humid weather conditions especially in one of the hottest regions in the world such as Saudi Arabia.  In addition, these studies did not address the application of PSM technology in Saudi Arabia with considering different factors such as physical body parameters (age, height and weight); their status (fasting or not); working shifts (indoors and outdoors); and assigned tasks. The proposed research addressed seven real site measurements including 35 different participants during the hottest periods of 2015 and 2016 in Al-Dhahran, Eastern Provence, Saudi Arabia. The results of the conducted measurements and analysis lead to conclude that:

- Different workers have different responses and behaviors under same working conditions. Therefore, it is important to apply real time monitoring system and individual practical working thresholds.
- Interventions including resting, hydration and self-pace have a major impact on workers' physiological records when work activity intensity is higher than the acceptable level (moderate intensity).

## 5.3 Research Contributions

The analysis results of the proposed research add more knowledge regarding the application of PSM technology for assessing the impacts of extremely hot and humid weather conditions on construction workers' health and safety. The technology has not been applied under such weather conditions, like in Saudi Arabia. Furthermore, working environment is totally different where construction workers in Saudi Arabia come from different countries, who have different responses and behaviors to such extreme weather. The contributions to the knowledge are illustrated in the following points:

- Provide a quantitative assessment for construction workers' health and safety in Saudi Arabia.
- Conduct real construction site measurements for the first time in Saudi Arabia.
- Application for PSM technology for the first time in assessing the construction workers' health and safety in Saudi Arabia.
- Addressing the for the first time the impact of extremely hot weather conditions on fasting workers.
- Introduces a comparison between construction workers' behaviors under harsh weather conditions in regards to the type of activities (indoors/outdoors activities), working shifts (morning and night shifts), and assigned tasks.
- Help in clarifying whether there is a significant difference in workers' behaviors and responses, who are working in the same conditions.
- A comprehensive literature about the weather conditions impacts on construction workers and the applications of new technologies in physiological status monitoring (PSM) in construction industry.

The contributions to the practical implementation are illustrated in the following points:

- Provide a quantitative assessment for construction workers who are performing their tasks in real construction sites in Saudi Arabia by conducting real site measurements.

- Identify the acceptable physiological bonds and heart rate zones for the cases under study.
- Provide some valuable recommendations based on the results of the conducted measurements.
- Help in clarifying whether it is suitable to adopt practical working thresholds for construction workers under extremely hot weather conditions.

## 5.4 Recommendations

For enhancing construction workers' health and safety under extremely hot and humid weather conditions in general and in Saudi Arabia the following recommendations should be considered:

- There is a high need to adopt real time monitoring system for construction workers in Saudi Arabia especially under extremely hot and humid weather conditions.
- Good scheduling of assigned tasks and working shifts could reduce the impact of extremely hot and humid weather in Saudi Arabia. With considering assigned tasks and degree of temperature and humidity in addition to workers' physiological parameters.
- It is highly recommended to adopt real time monitoring system and individual working threshold based on the physiological responses of the workers especially under extremely hot and humid weather conditions in Saudi Arabia, rather than depending on fixed working limits for certain degrees of temperature.

- Outdoors and morning working activities should not be assigned to fasting workers. Furthermore, the site management should assign light working activities to be performed during morning shifts in the hottest session.
- It is highly recommended under extremely hot and humid weather conditions to keep construction workers within safe working zones to schedule resting periods and provide cold water for workers in the site as well as self-pace.
- For future researches, it is recommended to include more fasting workers and wide range of activities. In addition, proposing an integration of three different aspects will add more knowledge. These aspects included motion and time analysis for designing the work methods of the construction industry. Productivity level identification of construction activities in order to build reference standards for wide range activities through synchronizing video records and physiological measurements as well as applying motion and time analysis. Moreover, the results of construction activities productivity assessment will be compared with the international standards for that activities. The results of this part will be used to build a new reference for construction workers' productivity with considering new factors such as physical body parameter (height, weight, fitness levels and others), working shifts (night and morning working shifts), indoors and outdoors activities.
- It is recommended for future researches to consider the following aspects:
    - Fasting workers and wide range of activities.
    - Productivity level and reference standards.
    - Motion and time analysis with synchronizing video records.
    - New designs for the PSM sensors.

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# Vitae

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# Appendixes

## Appendix-A: Detailed explanation about the required variables in data analysis.

### 1. Expected Maximum Heart Rate ($HR_{max}$).

The maximum heart rate represents temporary status of human body at which the individual experience maximum effort exertion i.e. maximum heart rate denotes to that the human body is under the highest possible of activities/work intensity (Hottenrott, K., 2007). HR max can also be defined as the highest value of human HR that can be achieved under high levels of exertion. Maximum heart rate is varied from person to another based on different factors such as age, physical body parameters, fitness level, type of activities, environmental factors such as temperature and humidity, health conditions … etc. According to Hottenrott, K. (2007) the most commonly used equation for predicting maximum heart rate is ($HR_{max} = 220 - age$) (see Table ) and most of the valid formulas estimate maximum heart rate based on age of the person as illustrated in Table .

**Table A1: Common equations of maximum heart rate estimation.**

| Author | Equation | Population |
|---|---|---|
| Roja, et al. (2006) | $HR_{max} = 220 - age$ | Small group men/women. |
| Robergs, & Landwehr (2002) | $HR_{max} = 216.6 - (0.84 \times age)$ | Men/Women (4-34 years). |
| Tanaka, et al. (2001) | $HR_{max} = 208 - (0.7 \times age)$ | Healthy adults |
| Gellish, et al. (2007) | $HR_{max} = 207 - (0.7 \times age)$ | Different ages and fitness level of adults from both gender in fitness program. |
| Gulati et al. (2010) | $HR_{max} = 206 - (0.88 \times age)$ | Stress test for middle-aged women. |
| Wohlfart and Farazdaghi (2003); Lee and Migliaccio (2014) | $HR_{max} = 203.7 / (1 + \exp(0.033 \times (\text{age} - 104.3)))$ | Men |
| Farazdaghi and Wohlfart (2001) | $HR_{max} = 190.2 / (1 + \exp(0.0453 \times (\text{age} - 107.5)))$ | Women |

Table  illustrates a sample of the maximum heart rate for athletes compared to the expected value that is calculated based the following formula ($HR_{max} = 220 - age$). The maximum heart rate value may reach to 200 (bpm) or greater than 200.

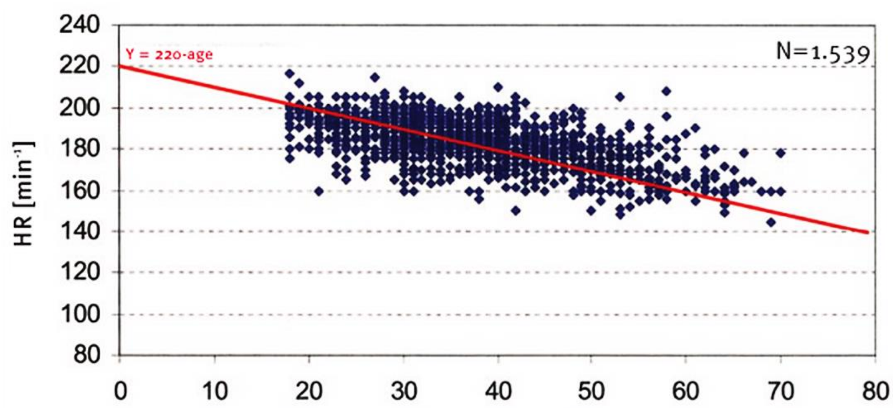


**Figure A1: $HR_{max}$ of sample of athletes (Hottenrott, K., 2007).**

## 2. Target Heart Rate ($THR$).

Target Heart Rate ($THR$) is defined as the optimal interval for heart rate in which human body is considered in a moderate activity intensity (Hottenrott, K., 2007). In this study, $THR$ will be employed in identifying the optimal intervals of heart rate in which construction worker's performing their tasks without any risks on their health with considering working under harsh weather conditions. $THR$ can be calculated based on Karvonen's formula (Lee & Migliaccio (2014)) as it is shown in the following:

$$THR = \left((HR_{max} - HR_{min.\ rest}) \times intesity\%\right) + Avg.HR_{rest} \quad (14)$$

## 3. Acceptable HR zones.

Acceptable HR zones represent the $THR$ acceptable intervals with considering desired level of work intensity. In construction industry, the desired intensity level is within 60-70% as it was addressed by Karvonen (1957) and Lee & Migliaccio (2014). In this study, we considered both 60-70% and 70-80% such that in both intervals high productivity levels and good performance level as well as positive pressure as illustrated in Table A3. Acceptable HR zones is calculated by using the following formula:

$$THR = \left((HR_{max} - HR_{min.\ rest})\times 60\%\right) + Avg.HR_{rest} \tag{15}$$

$$THR = \left((HR_{max} - HR_{min.\ rest})\times 70\%\right) + Avg.HR_{rest} \tag{16}$$

Or

$$THR = \left((HR_{max} - HR_{min.\ rest})\times 70\%\right) + Avg.HR_{rest} \tag{17}$$

$$THR = \left((HR_{max} - HR_{min.\ rest})\times 80\%\right) + Avg.HR_{rest} \tag{18}$$

### 4. Heart Rate Reserve ($HRR$).

Reserve heart rate denotes to the difference between the maximum heart rate and the resting heart rate (Hottenrott, K., 2007). HRR value varies based on the age of the individual and fitness level such that its value for well-trained athletes may reach to 150 bpm or grater and in some cases, may reach to 50 bpm or less as illustrated in the following figure.

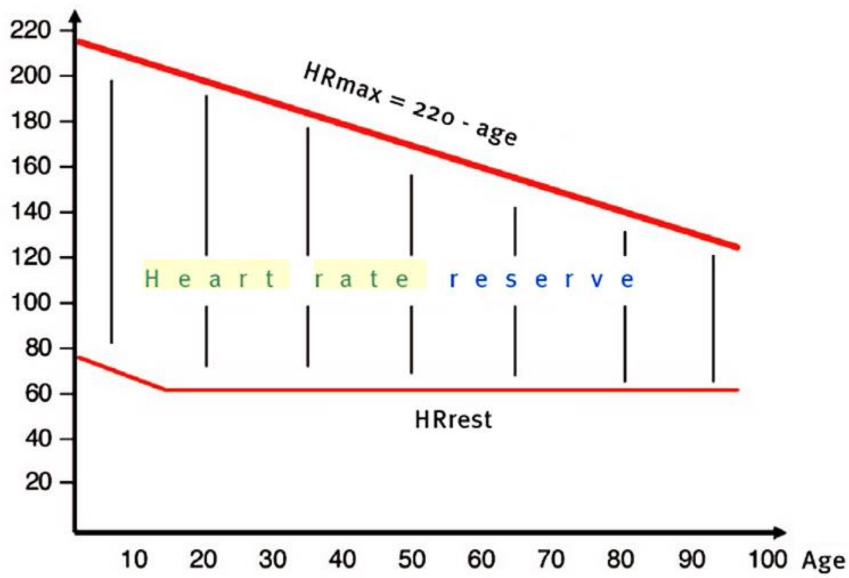


**Figure A1: HRR at different ages (Hottenrott, K., 2007).**

Large values of HRR indicate to high performance and low levels of HRR denote to low performance from the person under the study.

## 5. Resting Heart and Breathing Rate.

Resting heart rate is the minimum value of heart rate when the human body does note performing any activity or in resting status without exposing to any exertion. Resting heart rate also considered as one of the key physiological status of the human body. Similar to maximum heart rate and heart rate reserve, $HR_{resting}$ values change with the age of the individual as it is addressed in "National Health Statistics Reports" in US (Ostchega, et al., 2011) (see Figure A2).

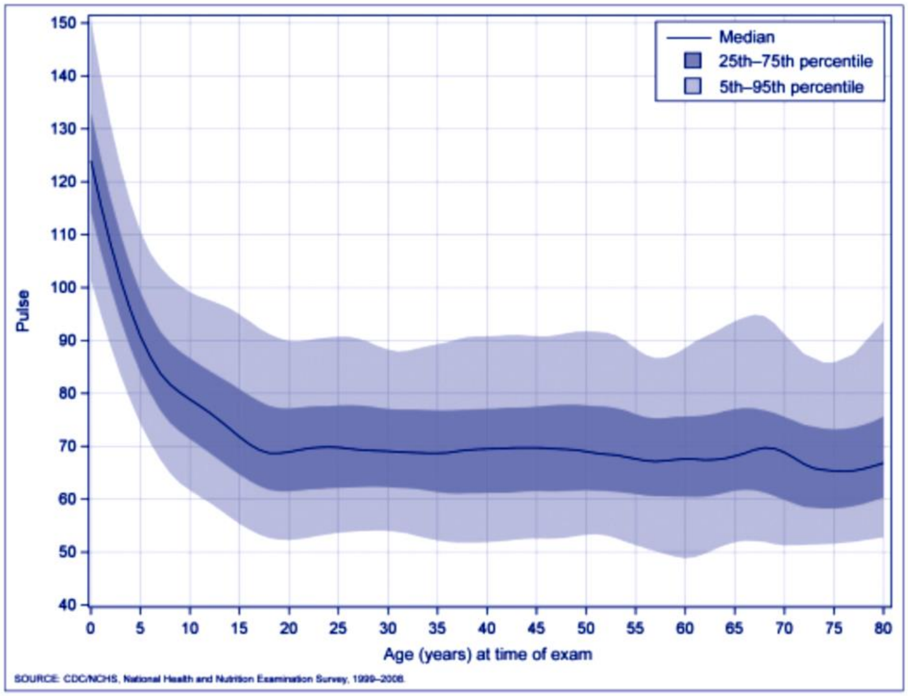


**Figure A2: Resting heart rate for mail in US (Ostchega, et al., 2011).**

Another suggested value for resting heart rate was addressed by Levy, et al. (1998) where the authors argued that, Resting heart rate for healthy young men whose ages between 24 to 32 years is 68 ± 6 bpm which is close to the chart shown in Figure A2 at 5$^{th}$ – 95$^{th}$ percentile. Resting breathing rate $BR_{resting}$ also used as an indicator for physiological status of individuals where its value change with the age of the person as it is illustrated in the following Table (Cichero & Murdoch, 2006).

**Table A2: Resting BR at different ages (Cichero & Murdoch, 2006).**

| Age | $BR_{rest}$ | $BR_{SD}$ |
|---|---|---|
| 0-1 | 39 | 11 |
| 1-2 | 30 | 6 |
| 2-3 | 28 | 4 |
| 3-4 | 25 | 4 |
| 4-5 | 27 | 5 |
| 5-6 | 23 | 5 |
| 6-7 | 25 | 5 |
| 7-8 | 24 | 6 |
| Adult Men | 19.4 | 4 |
| Adult Women | 20.9 | 3.9 |

## 6. Maximal Oxygen Uptake ($VO_{2_{max}}$).

Maximal oxygen uptake ($VO_{2_{max}}$) is a measure for human bodies' ability to take oxygen while they performing their activities in order to complete energy production circulation. Achten & Jeukendrup (2003) addressed that in the last 50-60 years, $VO_{2_{max}}$ was estimated based on the value of heart rate ($HR_{maximum}$ and $HR_{resting}$). Uth, et al. (2004) validated an estimation formula that is used for calculating maximum oxygen uptake as illustrated in the following:

$$VO_{2_{max}} \approx 15.0\ (\frac{mL}{Kg \times min}) \times \frac{HR_{max}}{HR_{rest}} \tag{19}$$

Where, $HR_{max}$ and $HR_{rest}$ denote to the maximum heart rate and "the lowest value of any 1-min average during the 5-min sampling period", respectively. In this study, we suggested using both minimum value of resting heart rate $HR_{min.\ rest}$ and average value of resting heart rate $Avg.HR_{\ rest}$ as it is illustrated in the following:

$$VO_{2_{max}} \approx 15.0\ (\frac{mL}{Kg \times min}) \times \frac{HR_{max}}{HR_{min.\ rest}} \tag{20}$$

$$VO_{2_{max}}^{*} \approx 15.0\ (\frac{mL}{Kg \times min}) \times \frac{HR_{max}}{Avg.HR_{\ rest}} \tag{21}$$

The suggested formulas were validated to another method for calculating $VO_{2_{max}}$ in which maximum oxygen uptake was calculated by OmniSense Analysis V3.9.6 software such that this software calculates $VO_{2_{max}}$ based on the following formula:

$$VO_{2_{max}} = 0.869 \times (3.5\ +\ (0.2 \times \mathrm{v}))\ +\ (\mathrm{V} \times \mathrm{G} \times 0.9)\ -\ 0.07 \tag{22}$$

Where V and G denote to velocity in meters per minute and grade Constant 5% (0.05), respectively (OmniSense Analysis Help, 2015 ).

### 7. Metabolic Equivalents (METs).

Metabolic Equivalents (METs) denotes to the rate of oxygen consumed at rest to 3.5 ml of oxygen per unit of body weight (kg) per min (Byrne, et al., 2005). METs can be calculated by using the following formula:

$$\text{METs} = \frac{VO_{2_{max}}}{3.5\ mL.Kg^{-1}.min^{-1}} \tag{23}$$

Both HR and METs are considered as absolute measures for different activities intensity levels with regarding different influential factors such as environmental conditions and types of performed activities. METs values are varies based on the performed activities such that METs value during quite sitting is 1 METs and during high intensity activities is between 9 to 20 METs or may greater than 20 METs (Norton, et al., 2010). Table 4.2 illustrates different work intensity categories and the related METs, $HR_{max}$, $HRR$, and $VO_{2_{max}}$ values. Figure 4.18 represents an index for identifying activity intensity level based on METs value (horizontal axes) and $VO_{2_{max}}$ (vertical axes).

### 8. Acceptable HR and BR physiological bounds.

Acceptable HR and BR physiological bounds it acceptable HR and BR ranges of human body in which the workers will not expose “to cardiovascular overload or overexertion” while they are performing their tasks. (Lee & Migliaccio, 2014). In this study, we follow the same approach that is proposed by Lee & Migliaccio, (2014) where the authors applied the following formulas to identify acceptable HR and BR physiological bounds.

$$HR_{min} = HR_{\min resting\ session} - \left(2 \times HR_{SD\ resting\ session}\right) \tag{24}$$

$$HR_{max} = HR_{\max working\ session} + (2 \times HR_{SD\ working\ session}) \tag{25}$$

$$BR_{min} = BR_{\min resting\ session} - \left(2 \times BR_{SD\ resting\ session}\right) \tag{26}$$

$$BR_{max} = BR_{\max working\ session} + (2 \times BR_{SD\ working\ session}) \tag{27}$$

## 9. Desired and estimated activity intensity level.

World Health Organization defined activity intensity as “the rate at which the activity is being performed or the magnitude of the effort required to perform an activity or exercise” (Global Strategy on Diet, Physical Activity and Health, 2015).

Desired activity level as it is addressed by Karvonen (1957) and Lee & Migliaccio, (2014) should be within 60-70% of the activity intensity percentage i.e. zone 2 in order to achieve high productivity level from the workers. Estimated activity intensity can be identified based on maximum oxygen uptake ($VO2max$) and metabolic equivalents (METs) which was applied to identify activity zone by using activity intensity index that is shown in Figure 4.18 and consequently, activity intensity level was identified by using the classification illustrated in Table A3.

**Table A3: Different activity intensity zones.**

| Zone Index | Activity Intensity % | Color Index | Zone | Description |
|---|---|---|---|---|
| 1 | ]50:60%] | Yellow | Sedentary Intensity | Related to sitting based activities such as reading, watching, deriving car …etc., considered as a safe and conformable heart rate zone for workers (Norton, et al., 2010; Lee and Migliaccio, 2014). |
| 2 | ]60:70%] | Orange | Light Intensity | Light activities and duties (Norton, et al., 2010) provide high productivity level (Lee and Migliaccio, 2014). |

**Table A3: Different activity intensity zones.**

| Zone Index | Activity Intensity % | Color Index | Zone | Description |
|---|---|---|---|---|
| 3 | ]70:80%] | Coral | Moderate Intensity | Hard normal work with achieving a good performance level and provide positive pressure (Lee and Migliaccio, 2014). |
| 4 | ]80:90%] | Light Red | Vigorous Intensity | Physical activities such as heavy lifting which cause difficulty in breathing and high levels of physiological stress (Norton, et al., 2010). Considered as unsafe zone (Lee and Migliaccio, 2014). |
| 5 | ]90:100%] | Dark Red | High Intensity | The most hazardous zone in which the individuals cannot control their behaviors and they need a quick medical care to become in lower zones (Lee and Migliaccio, 2014). |

## 10.Body mass index (BMI)

Body mass index (BMI) defined as human body mass in kilograms for each square meter of height square ($m^2$). BMI can be calculated as by dividing body weights in ($kg$) by the height square in ($m^2$) as it is illustrated in the following formula:

$$BMI = \frac{Weight\ (kg)}{(Height\ (m))^2} \tag{28}$$

BMI is an accurate indicator for human body fitness and obesity level and general health status. Per "World Health Organization categorization", there are four categories for fitness level based on BMI as illustrated in the following table (Clark, et al., 2002):

**Table A4: Body mass index categories (Clark, et al. 2002).**

| Category # | Classification | BMI ($kg/m^2$) |
|---|---|---|
| 1 | Normal | < 25 |
| 2 | Overweight | [25:30[ |
| 3 | Obese | [30:39[ |
| 4 | Morbidly obese | ≥ 39 |

## 11. Body fat percentage (%Fat)

BMI does not consider as an accurate measure for human body fitness and obesity level without taking in account percentage of fat. Both BMI and %Fat provide a simple measure for human body fitness level and obesity in addition both indicators have a significant relation in “trained and untrained” people (Mazic, et al., 2009). These two factors are used for assessing human body fitness level in physiological status monitoring experiments as it was applied in construction industry by Lee & Migliaccio (2014) where the authors apply the following formula which was retrieved from Deurenberg, et al. (1991) study.

$$\%Fat = (1.20 \times BMI) + (0.23 \times Age) - (10.8 \times Gender) - 5.4 \qquad (29)$$

## Appendix-B: Pilot Study

In this section, we introduce a pilot study which was conducted in order to be familiar with Zephyr technology (sensors and software). In addition, the proposed statistical analysis was applied on the recorded data in order to represent a clear view about the final form of the expected results and outcomes of the proposed study in a real construction site.

### 1. Introduction

Training measurements were conducted on 4 Jun 2015 at night (from 07:12 to 07:47 P.M.) with including five students from KFUPM who volunteered to this recording session. The participants have the same nationality (Yemeni) where they were asked to be monitored by Zephyr belts while they are playing a football game at KFUPM. The required data about participants' age and body parameters are summarized in Table B1.

**Table B1: Training measurements participants.**

| No. Participant | Age | Sex (M/F) | Height (ins) | Weight (Ibs) | Fitness Level |
|---|---|---|---|---|---|
| 1 | 33 | M | 66.14 | 181.88 | 5 |
| 2 | 32 | M | 67.7 | 165 | 5 |
| 3 | 29 | M | 67.7 | 187.39 | 5 |
| 4 | 23 | M | 68 | 130 | 5 |
| 5 | 22 | M | 69.29 | 160.9 | 5 |

Weather conditions of this date were retrieved from "Weatherspark" website based on "King Abdulaziz Air Base (Dhahran International Airport)" records. The proposed measurements were taken place between 7 to 8 P.M. where the maximum degree of temperature is 45°C, average degree of temperature is 41°C and minimum degree of temperature is 21°C. Also, the maximum, average and minimum humidity levels were 49%, 21% and 13%, respectively. The hourly average degree of temperature on this day is illustrated in Table B2.

**Table B2: Temperature and humidity of training measurements. (Source: weatherspark.com)**

| Time (hr.) | Avg. Temperature (°C) | Humidity % |
|---|---|---|
| 7 P.M. | 36 | 21 |
| 8 P.M. | 35 | 22 |

## 2. Procedures and Data Collection

The required measurements were conducted through an organized process started by preparing the software, echo gate and charging Zephyr sensors. Preparation process includes update Zephyr software in both computer and sensors by using three different software applications which are “Zephyr Configuration Tool” and “OmniSense Analysis” in addition to “OmniSense Live” such that it is necessary to enter the required data for each participant. These data are related to participants’ first and last name; age; sex, height (inches); weight (Ibs); and fitness level should be identified and entered to the required fields as it is shown in Figure B.

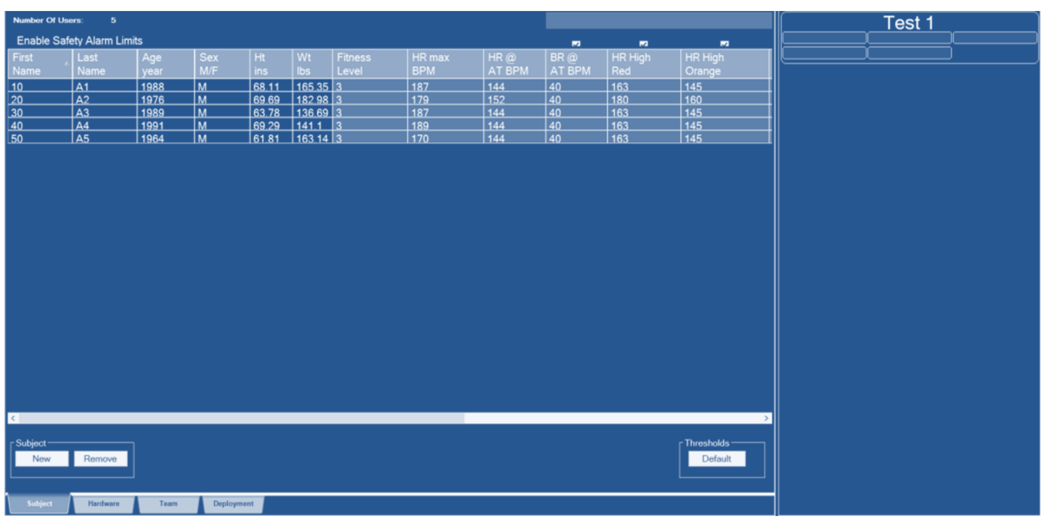


**Figure B1: Required data for OmniSense Live software.**

The required data for the first six fields are measured directly by asking the participants about their names/ages and by measuring their height and weight. Moreover, there is a skill from 0 to 10 in “OmniSense Live” used as indicator for the fitness level of the participants.

In this study, it is assumed that all participants have normal fitness level 5. In addition, fitness level can be calculated by using "OmniSense Analysis" after collecting the data. The other fields (Heart Rate maximum, Breathing Rate @ AT) was calculated and updated after and/or during recording the data by "OmniSense Analysis". One ECHO and one ECHO repeater are available to be used in the conducted measurements. Each one is able to cover up to 300 yard rang i.e. 600 yard totally (see Figure B2). Therefore, participants should be within this rang and ECHO repeater should be placed in 300 yard far from ECHO Gateway.

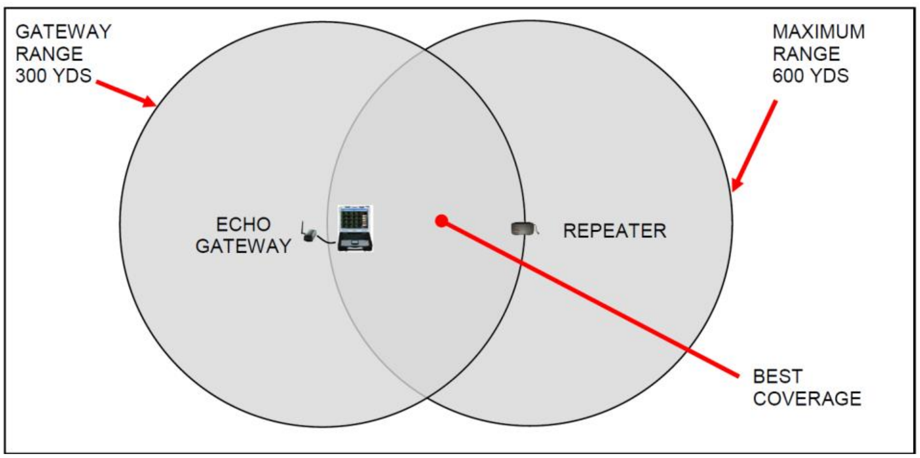


**Figure B2: ECHO gateway rang (Zephyr PSM User Training Guid, 2011).**

After preparing all required equipment and software, measurements are moved to another stage, which is wearing Zephyr belts by participants in such way must be comfortable and they can perform their activities normally. Based on Zephyr belts' users guide, Zephyr belts consists three different sensors (1) heart Rate (ECG) sensor, (2) breathing sensor; and accelerometer (3) (see Figure A3). Two main criteria should be considered in wearing Zephyr belts (tension and position of the belt on participants' body). Zephyr belts tension should be suitable for human body breathing such that the participant can breathe normally without suffering from shortness of breath as a result of belt tightness. In addition, it is important to position the belt in the center of the area under the participant's armpit with allowance around one inch in order to get the optimal signal detection from the sensors. It is necessary to check the signal directly from the "OmniSense Live" to make sure that all the sensors are connected to the software and they give the optimal signal.


**Figure A3: Zephyr belt sensors (Zephyr PSM User Training Guid, 2011).**

It is necessary to collect information about the participants' health conditions by asking them direct questions. In addition, participants' opinions about Zephyr belts were assessed directly by few questions describing their opinions.

## 3. Data Analysis

In this section, we address preliminary data analysis for the training measurements such that the acceptable HR and BR bounds and HR physiological zones was identified. Training measurements included five participants having different physical parameters and ages as it is illustrated in Table B1. The participants were asked seven questions in order to identify whether they have any health problem in addition to assessing their opinions about how they feel when they wear Zephyr belts. The following figure summarizes their responses.

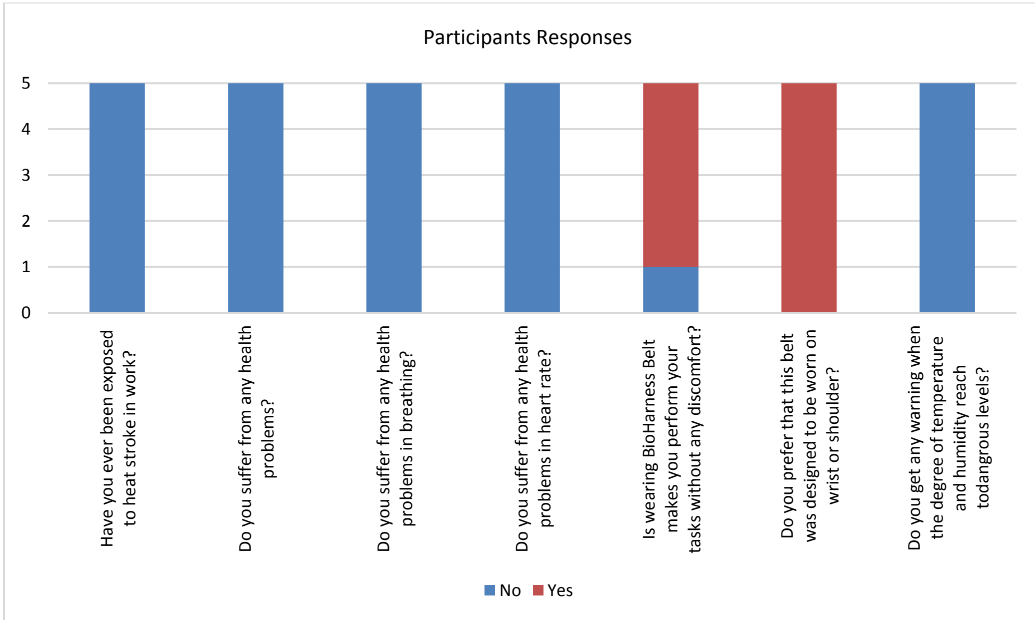


**Figure A4: Summary of participants' response in training measurement.**

Figure A4 illustrates that, the results of participants' response in training measurements reveals that they do not have any health problem regarding to heart and breathing diseases. In addition, four of the participants declared that wearing Zephyr belts does not create any discomfort and all participants preferred if Zephyr belt manufactured in such way that makes it possible to worn in wrist or shoulder and all of them do not get any warning signs when degree of temperature and humidity reach to dangerous levels.

The preliminary data were recorded during football match at on 4 Jun 2015 at night where the data recording starts at 07:12 P.M. and continued to 07:47 P.M (See Appendix-A). It is noticed that, there are some fluctuation in the first one minute such that HR value reached to zero. This non-reasonable variability in HR and BR values during the first one minutes is resulted from the time that it takes to adjust Zephyr belts to be fitted with participants' body in addition to the time that it takes to connect the sensors to the ECHO gate correctly. Therefore, the data that is recorded in the first minute was eliminated before analyzing the data. For these reasons, similar step is performed to eliminate the recorded data during the first minutes of each subject. Figure A5 represents a sample of the recorded data of subject 4 HR and BR.

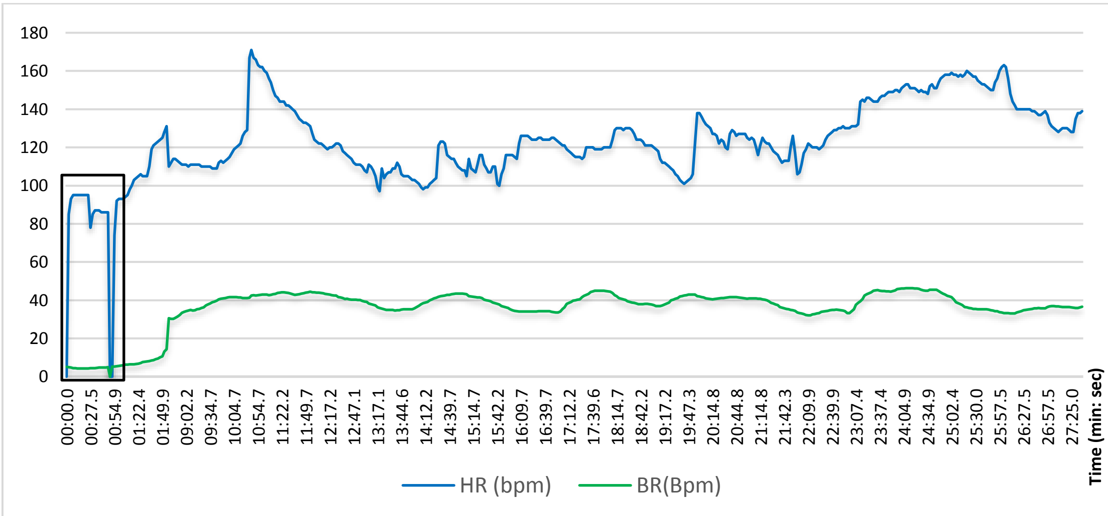


**Figure A5: Hourly HR and BR plot for subject 4 of the training measurements.**

The following figure illustrates the recorded data of the fourth subject's HR and BR after removing the first minute.

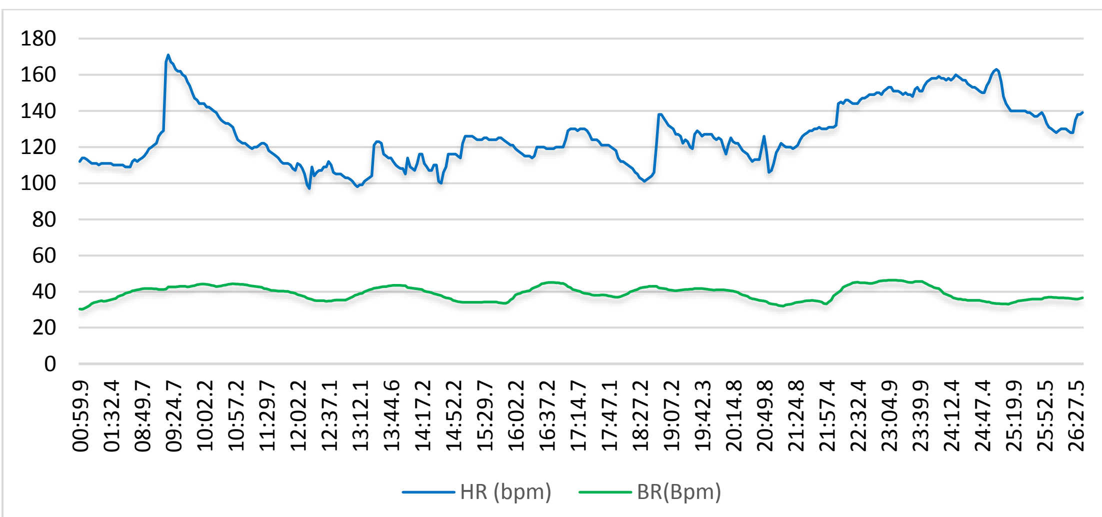


**Figure A6: Recorded data of the fourth subject's HR and BR after removing the first minute.**

- *Two-tailed Grubbs' Test*

Grubbs' test is a statistical test that is applied for removing the outliers from a set of data that have the tendency to follow normal distribution (Grubbs & Beck, 1972). Normal human body heart and breathing rate distribution tend to normal distribution. Therefore, Grubbs' test is applied to eliminate the outliers' points from the recorded data.

Two-tailed ("smallest and largest value is an outlier") Grubbs' test is conducted by using "Minitab® 17.1.0" software with significant level ($\alpha = 0.05$). Appendix-E includes Minitab's outputs of Two-tailed Grubbs' test for each subject. Minitab outputs for the first subject HR and BR reveals that there is not outlier in the recorded HR data as it is illustrated in Figure A7.

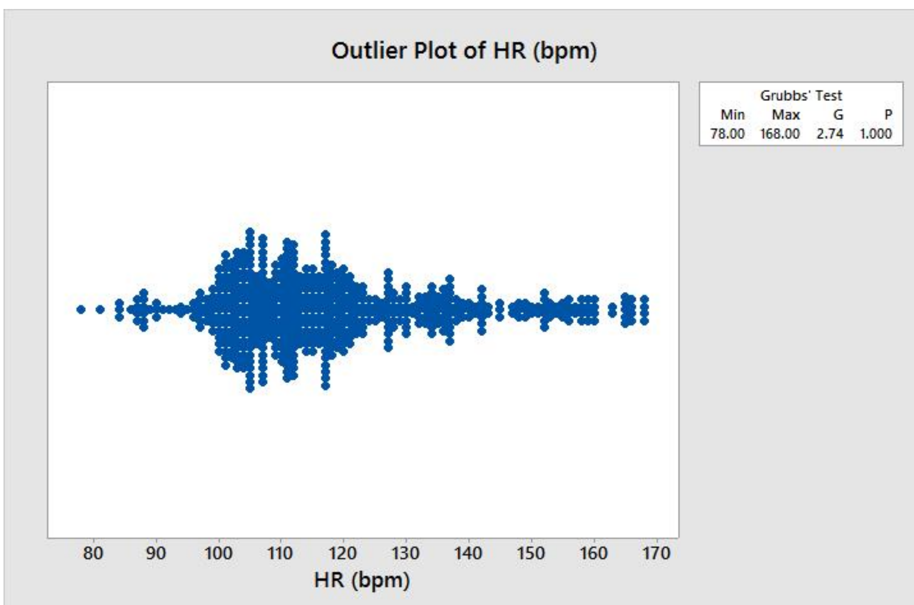


**Figure A7: Two-tailed Grubbs' test results for the first subject HR.**

The same result is appeared for BR of the first subject as it is illustrated in Figure A8.

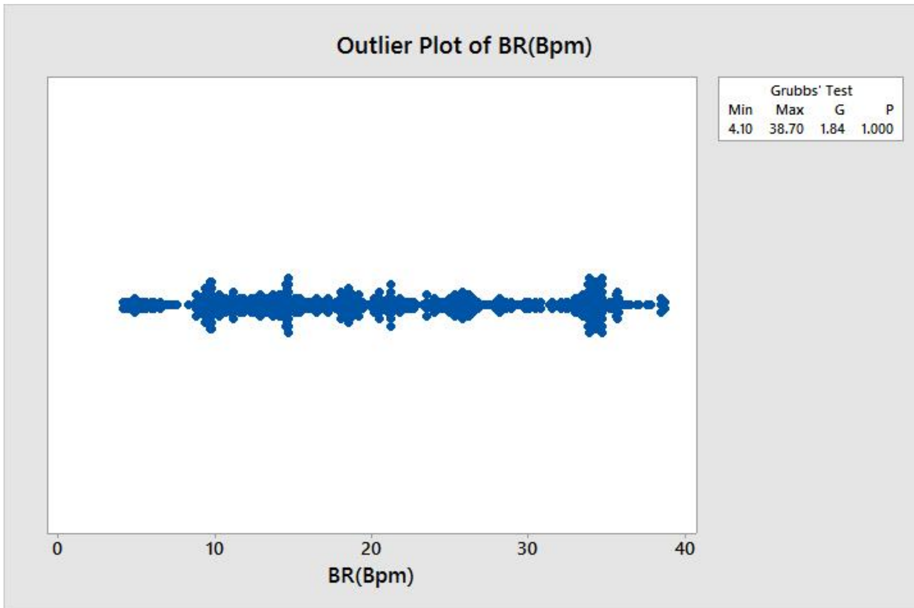


**Figure A8: Two-tailed Grubbs' test results for the first subject BR before removing outliers.**

The previous steps were applied for the remaining four subjects such that the first minute of the recorded data is eliminated at the first then outliers were eliminated. The results are of Two-tailed Grubbs' test for HR and BR for each participant are summarized in the following table.

**Table A3: Two-tailed ("smallest and largest value is an outlier") HR Grubbs' test results.**

| Type of Measurement | Subject # | HR / BR | P-Value | Decision | No. Outliers | From (min) | To (min) |
|---|---|---|---|---|---|---|---|
| Training Measurements | Recording starts at (07:12:47 P.M.) / Recording Time (00:34:24.9) | | | | | | |
| | 1 | HR | 1.000 | None | 0 | 1 | 34.42 |
| | | BR | 1.000 | None | 0 | | |
| | Recording starts at (07:12:47 P.M.) / Recording Time (00:32:52.4) | | | | | | |
| | 2 | HR | 1.000 | None | 0 | 1 | 32.87 |
| | | BR | 1.000 | None | 0 | | |
| | Recording starts at (07:12:47 P.M.) / Recording Time (00:29:50) | | | | | | |
| | 3 | HR | 1.000 | None | 0 | 1 | 29.83 |
| | | BR | 1.000 | None | 0 | | |
| | Recording starts at (07:12:47 P.M.) / Recording Time (00:27:37.6) | | | | | | |
| | 4 | HR | 1.000 | None | 0 | 1 | 27.63 |
| | | BR | 0.021 | Outlier | 22 | | |
| | Recording starts at (07:12:47 P.M.) / Recording Time (00:24:02.7) | | | | | | |
| | 5 | HR | 1.000 | None | 0 | 1 | 24.05 |
| | | BR | 1.000 | None | 0 | | |

In this study, we introduce different formulas that can be used to estimate different required variables in order to calculate acceptable HR and BR physiological bounds and heart rate zones for the conducted measurements as it is explained in the following:

1- Expected maximum heart rate ($HR_{max}$).
2- Acceptable HR and BR physiological bounds.
3- Target heart rate (THR).
4- Heart rate reserve (HRR).
5- Maximal oxygen uptake ($VO_{2_{max}}$).
6- Desired and estimated activity intensity level.
7- Resting Heart Rate.

- *Maximum heart rate ($HR_{max}$)*

In the literature, there are several valid formulas that can be used for estimating the maximum heart rate with considering different ages. In this study, we apply the most accurate formula (Wohlfart and Farazdaghi, 2003; and Lee and Migliaccio, 2014) that had been applied successfully in construction applications.

$$HR_{max} = 203.7 \,/\, (1 + \exp(0.033 \times (\text{age} - 104.3))) \quad (30)$$

Where, $HR_{max}$ denotes to expected maximum HR.

- *Target heart rate (THR).*

$$THR = \big((HR_{max} - HR_{min.\ rest}) \times intesity\%\big) + Avg.HR_{rest} \quad (31)$$

- *Heart rate reserve (HRR).*

$$HRR = Predicted\ HR_{max} - Avg.HR_{rest} \quad (32)$$

- *Body mass index (BMI)*

$$BMI = \frac{Weight\ (kg)}{(Height\ (m))^2} \quad (33)$$

- *Body fat percentage (%Fat)*

$$\%Fat = (1.20 \times BMI) + (0.23 \times Age) - (10.8 \times Gender) - 5.4 \quad (34)$$

- *Resting HR*

During training measurements, the participants had not resting session therefore, resting HR and BR is retrieved from published references. Resting heart rate for healthy young men whose ages between 24 to 32 years is 68 ± 6 bpm (Levy, et al., 1998) where BR is 19.4 ± 4 (Cichero & Murdoch, 2006).

- *Acceptable HR and BR physiological ranges.*

$$HR_{min} = HR_{\min resting\ session} - \left(2 \times HR_{SD\ resting\ session}\right) \quad (35)$$

$$HR_{max} = HR_{\max working\ session} + (2 \times HR_{SD\ working\ session}) \quad (36)$$

$$BR_{min} = BR_{\min resting\ session} - \left(2 \times BR_{SD\ resting\ session}\right) \quad (37)$$

$$BR_{max} = BR_{\max working\ session} + (2 \times BR_{SD\ working\ session}) \quad (38)$$

**Table A4: HR acceptable ranges for the training measurements.**

| Subject | $HR_{min}$ *resting session* | $HR_{SD}$ *resting session* | $HR_{max}$ *Training* | $HR_{SD}$ *Training* | Acceptable Rang (bpm) | |
|---|---|---|---|---|---|---|
| | | | | | $HR_{min}$ | $HR_{max}$ |
| 1 | 68 | 6 | 168 | 18.19 | 56 | 204 |
| 2 | | | 179 | 23.98 | 56 | 227 |
| 3 | | | 171 | 22.99 | 56 | 217 |
| 4 | | | 171 | 17 | 56 | 205 |
| 5 | | | 185 | 23.38 | 56 | 232 |

**Table A5: Breathing rate acceptable ranges for training measurements.**

| Subject | $BR_{min}$ *resting session* | $BR_{SD}$ *resting session* | $BR_{max}$ *working session* | $BR_{SD}$ *working session* | Acceptable BR Rang (bpm) | |
|---|---|---|---|---|---|---|
| | | | | | $BR_{min}$ | $BR_{max}$ |
| 1 | 19.4 | 4 | 38.7 | 9.563 | 11.4 | 57.8 |
| 2 | | | 41.2 | 8.453 | 11.4 | 58.1 |
| 3 | | | 38.5 | 7.095 | 11.4 | 52.7 |
| 4 | | | 46.3 | 3.95 | 11.4 | 54.2 |
| 5 | | | 47 | 6.825 | 11.4 | 60.7 |

- *Acceptable HR physiological zones.*

Acceptable HR physiological zones is calculated at the desired activity intensity (60: 70 %) at which is suitable for human body to perform their activities without any risks on their health. Quantitative assessment for HR of the participants and identifying the acceptable HR physiological bounds for each participant provides a good indicator about activity intensity zone and consequently the impact of weather conditions and their performance. Table A6 illustrates Acceptable HR physiological bounds for different participants.

**Table A6: Acceptable physiological zones of training measurements.**

| Subject | BMI | %Fat | Predicted | Resting Session | | | Training | | | Measured/ Predicted % | Acceptable HR Ranges | | HR zones | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | SD | Min | Mean | SD | Max | | Min | Max | Lower | Upper |
| 1 | 29.2 | 26.5 | 186 | 68 | 6 | 54 | 118 | 18 | 168 | 90% | 56 | 204 | 144 | 159 |
| 2 | 25.3 | 21.5 | 187 | 68 | 6 | 53 | 130 | 24 | 179 | 96% | 56 | 227 | 157 | 175 |
| 3 | 28.7 | 25.0 | 188 | 68 | 6 | 55 | 118 | 23 | 171 | 91% | 56 | 217 | 152 | 168 |
| 4 | 19.8 | 12.8 | 191 | 68 | 6 | 52 | 126 | 17 | 171 | 90% | 56 | 205 | 144 | 159 |
| 5 | 23.6 | 17.1 | 191 | 68 | 6 | 52 | 135 | 23 | 185 | 97% | 56 | 232 | 160 | 178 |

The physiological parameters HR and BR were used as an indicator for impacts of weather conditions on participants' health and safety such that the participants were exposed to high risk and heat illnesses when HR and BR values exceeds the physiological thresholds. Based on the calculated physiological thresholds, percentage of records exceeding these thresholds can be identified as it is illustrated in Table A7 and

**Table A7: Percentage of records exceeding physiological thresholds.**

| Subject | % Exceeding HR ranges | % Exceeding BR ranges | % Exceeding HR zones |
|---|---|---|---|
| 1 | 0 % | 19 % | 3 % |
| 2 | 0 % | 5 % | 2 % |
| 3 | 0 % | 5 % | 1 % |
| 4 | 0 % | 5 % | 3 % |
| 5 | 0 % | 0 % | 5 % |

- *Maximum oxygen uptake ($VO_{2_{max}}$) level.*

Maximum oxygen uptake ($VO_{2_{max}}$) level is calculated by identifying the maximum oxygen uptake ($VO_{2_{max}}$). $VO_{2_{max}}$ can be calculated based on the result of maximum heart rate in training session $HR_{max}$ divided by minimum heart rate during rest session $HR_{rest}$ as it is shown in the following (Uth, et al., 2004):

$$VO_{2_{max}} \approx 15.0 \left(\frac{mL}{Kg\times min}\right)\times \frac{HR_{max}}{HR_{min.\ rest}} \quad (39)$$

In this study, we also applied the same approach of Broeder, et al. (1992), that $VO_{2_{max}}$ can be calculated by multiplying the ratio between maximum heart rate in training session $HR_{max}$ and average heart rate during rest session $Avg.HR_{rest}$ as it is shown in the following:

$$VO_{2_{max}}^{*} \approx 15.0 \left(\frac{mL}{Kg\times min}\right)\times \frac{HR_{max}}{Avg.HR_{rest}} \quad (40)$$

- *Metabolic equivalents (METs).*

$$\text{METs} = \frac{VO_{2_{max}}}{3.5\ mL.Kg^{-1}.min^{-1}} \quad (41)$$

**Table A8: Actual and expected maximum oxygen uptake level and metabolic equivalents (METs) of training measurements.**

| Subject | Actual $VO_{2_{max}}$ | $HR_{\min at\, rest}$ | $Avg.HR_{rest}$ | $HR_{max}$ | $VO_{2_{max}}$ | $VO_{2_{max}}^{*}$ | Actual METs | METs | METs* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 82.1 | 54 | 68 | 168 | 47 | 37 | 23 | 13 | 11 |
| 2 | 68.68 | 53 | 68 | 179 | 51 | 39 | 20 | 14 | 11 |
| 3 | 41.83 | 55 | 68 | 171 | 47 | 38 | 12 | 13 | 11 |
| 4 | 31.09 | 52 | 68 | 171 | 49 | 38 | 9 | 14 | 11 |
| 5 | 25.72 | 52 | 68 | 185 | 53 | 41 | 7 | 15 | 12 |

- *Desired, actual and estimated activity intensity.*

Desired activity level as it is addressed by Karvonen, M. J. (1957) and Lee & Migliaccio (2014) should be within 60-70% of the activity intensity percentage i.e. zone 2 in order to make the participants performing their tasks with high levels of productivity under light intensity. Five different zones are listed from the lowest to the highest intensity in Table A3, Activity intensity can be calculated by different methods. The first method applied in this study is by using activity intensity zones index (see Figure 4.18) as an index to identify activity intensity level based on two variables $VO_{2_{max}}$ and METs. For identifying in which zone the workers are during training session, it is required to calculate both $VO_{2_{max}}$ and METs of each participant as it is illustrated in Table 4.2. Then, activity intensity zone was indented by using Figure 4.18.

By using activity intensity index (Figure 4.18), we can identify to which category the performed activities are related. To enhance, for the first subject the calculated maximum oxygen uptake ($VO_{2_{max}}$) and metabolic equivalents (METs) are 35 and 10, respectively. This two values dente to a point in the dark red region in Figure 4.18 at the highest intensity zone. The same procedures are followed for the other values of $VO_{2_{max}}$ and METs of each subject. The results of identifying the activity intensity zones are summarized in Table A9.

**Table A9: Actual and calculated activity intensity of the training measurements.**

| Subject | Actual Zone | | | Calculated Zone | | | Calculated Zone* | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity |
| 2 | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity |
| 3 | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity |
| 4 | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity |
| 5 | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity | 5 | ]90:100%] | High Intensity |

## 4. Result Discussion and Conclusion

Participants' responses for the questions reveal that, they do not have any warning system to warn them when weather conditions (heat and humidity) reach to dangerous levels that may threaten their health. Adopting such system in Saudi Arabia will help in protecting athletes from overexertion and heat illnesses. Furthermore, the application of equation (3) for estimating maximum HR provides an accurate estimation. This result supports the argument that equation (3) provides the most accurate estimation for $HR_{max}$ where the minimum value of (Measured/ Predicted %) ratio is 90%. Similar conclusion was addressed by Wohlfart and Farazdaghi (2003); and Lee and Migliaccio (2014). Moreover, there are not any HR records exceeded HR range which indicate to that participants HR were under the acceptable range of the heart rate. On the other hand, there are some BR records exceeded acceptable range of the breathing rate in addition to some HR records exceed the acceptable HR zones which indicate that the participants exposed to high intensity levels more than the 60-70%. A further analysis was conducted to identify the estimated and actual activity intensity level under harsh weather conditions. All participants are exposed to the highest intensity level which is the most hazardous region in which the participants are not able to control their behaviors and they need a quick medical care to become in lower zones.

## Appendix-C: Site measurements recorded data and analysis.

### 1. Construction site measurements participants' and weather data.

This section of the appendixes includes the recording time of the conducted measurements and the participants' information including their body parameters and status as well as type of work activity. In addition, this section includes the summary of the weather conditions that are related to the conducted measurements.

**Table C1: First and second construction site experiments participants' data.**

| | Participant # | Record Start A.M. | Record Time hr :min | Nationality | Activity | Status | Age Year | Ht (ins) | Wt (Ibs) | Fitness Level |
|---|---|---|---|---|---|---|---|---|---|---|
| First Site Measurement | 1 | 09:50 | 04:48 | Pakistani | Structure installation and filter preparing. | Fasting | 33 | 74.80 | 198.42 | 5 |
| | 2 | 09:56 | 04:41 | Pakistani | | Fasting | 34 | 66.54 | 176.37 | 5 |
| | 3 | 10:01 | 02:57 | Nepalese | | Normal | 42 | 68.11 | 178.57 | 5 |
| | 4 | 10:03 | 04:35 | Indian | | Normal | 27 | 67.32 | 187.39 | 5 |
| | 5 | 10:05 | 04:33 | Nepalese | | Normal | 30 | 64.57 | 165.35 | 5 |
| Second Site Measurement | 1 | 09:43 | 04:33 | Pakistani | Structure installation and filter preparing. | Fasting | 24 | 67.72 | 143.30 | 5 |
| | 2 | 09:46 | 04:30 | Nepalese | | Normal | 36 | 59.06 | 154.32 | 5 |
| | 3 | 09:49 | 04:28 | Indian | | Normal | 29 | 66.54 | 145.51 | 5 |
| | 4 | 09:09 | 05:07 | Indian | | Normal | 37 | 68.50 | 119.05 | 5 |
| | 5 | 09:53 | 04:24 | Indian | | Normal | 51 | 61.81 | 163.14 | 5 |

**Table C2: Hourly temperature and humidity for the first two sites experiments (Source: weatherspark.com).**

| | Time (hr.) | Avg. Temperature (°C) | Humidity % | Time (hr.) | Avg. Temperature (°C) | Humidity % |
|---|---|---|---|---|---|---|
| First Site Measurement | 12 A.M. | 30 | 18 | 12 P.M. | 44 | 7 |
| | 1 A.M. | 29 | 19 | 1 P.M. | 44 | 7 |
| | 2 A.M. | 29 | 15 | 2 P.M. | 43 | 8 |
| | 3 A.M. | 29 | 19 | 3 P.M. | 42 | 11 |
| | 4 A.M. | 27 | 19 | 4 P.M. | 41 | 12 |
| | 5 A.M. | 27 | 19 | 5 P.M. | 40 | 12 |
| | 6 A.M. | 29 | 19 | 6 P.M. | 39 | 12 |
| | 7 A.M. | 33 | 11 | 7 P.M. | 38 | 12 |
| | 8 A.M. | 35 | 13 | 8 P.M. | 37 | 12 |
| | 9 A.M. | 39 | 9 | 9 P.M. | 35 | 14 |
| | 10 A.M. | 41 | 10 | 10 P.M. | 34 | 15 |
| | 11 A.M. | 43 | 8 | 11 P.M. | 33 | 14 |

**Table C2: Hourly temperature and humidity for the first two sites experiments (Source: weatherspark.com).**

| | Time (hr.) | Avg. Temperature (°C) | Humidity % | Time (hr.) | Avg. Temperature (°C) | Humidity % |
|---|---|---|---|---|---|---|
| Second Site Measurement | 12 A.M. | 32 | 16 | 12 P.M. | 43 | 8 |
| | 1 A.M. | 30 | 18 | 1 P.M. | 43 | 9 |
| | 2 A.M. | 29 | 22 | 2 P.M. | 42 | 9 |
| | 3 A.M. | 29 | 19 | 3 P.M. | 42 | 11 |
| | 4 A.M. | 29 | 18 | 4 P.M. | 41 | 11 |
| | 5 A.M. | 29 | 20 | 5 P.M. | 40 | 11 |
| | 6 A.M. | 30 | 14 | 6 P.M. | 38 | 13 |
| | 7 A.M. | 33 | 12 | 7 P.M. | 36 | 14 |
| | 8 A.M. | 35 | 11 | 8 P.M. | 35 | 14 |
| | 9 A.M. | 38 | 11 | 9 P.M. | 34 | 14 |
| | 10 A.M. | 40 | 10 | 10 P.M. | 32 | 17 |
| | 11 A.M. | 42 | 9 | 11 P.M. | 31 | 21 |

**Table C3: Third construction site measurements participants' data.**

| | Participant # | Record Start P.M. | Record Time hr :min | Nationality | Activity | Status | Age Year | Ht (ins) | Wt (Ibs) | Fitness Level |
|---|---|---|---|---|---|---|---|---|---|---|
| Third Site Measurements | 1 | 09:58 | 04:38 | Philippine | Formwork | Normal | 27 | 68.11 | 165.35 | 5 |
| | 2 | 09:58 | 04:31 | Nepalese | Formwork | Normal | 39 | 69.69 | 182.98 | 5 |
| | 3 | 09:58 | 04:28 | Indian | Formwork | Normal | 26 | 63.78 | 136.69 | 5 |
| | 4 | 09:58 | 04:36 | Pakistani | Shoveling | Normal | 24 | 69.29 | 141.10 | 5 |
| | 5 | 09:58 | 04:26 | Bangladesh | Formwork | Normal | 33 | 66.14 | 180.78 | 5 |

**Table C4: Weather conditions for the third measurements (Source: weatherspark.com).**

| 27 Jun 2015 | | | 28 Jun 2015 | | |
|---|---|---|---|---|---|
| Time (hr.) | Avg. Temperature (°C) | Humidity % | Time (hr.) | Avg. Temperature (°C) | Humidity % |
| 12 P.M. | 41 | 11 | 12 A.M. | 29 | 26 |
| 1 P.M. | 41 | 12 | 1 A.M. | 28 | 40 |
| 2 P.M. | 41 | 12 | 2 A.M. | 29 | 33 |
| 3 P.M. | 40 | 12 | 3 A.M. | 28 | 33 |
| 4 P.M. | 39 | 15 | 4 A.M. | 28 | 33 |
| 5 P.M. | 38 | 14 | 5 A.M. | 27 | 33 |
| 6 P.M. | 37 | 16 | 6 A.M. | 28 | 28 |
| 7 P.M. | 35 | 16 | 7 A.M. | 32 | 18 |
| 8 P.M. | 34 | 18 | 8 A.M. | 36 | 14 |
| 9 P.M. | 33 | 20 | 9 A.M. | 38 | 13 |
| 10 P.M. | 33 | 21 | 10 A.M. | 41 | 12 |
| 11 P.M. | 31 | 26 | 11 A.M. | 43 | 9 |

**Table C5: Participants' data of 2016 construction site measurements.**

| Measurement | Participant # | Record Start | Record Time hr :min | Nationality | Activity | Age Year | Ht (ins) | Wt (Ibs) | Fitness Level |
|---|---|---|---|---|---|---|---|---|---|
| Fourth Site Measurement | 1 | 09:02 | 02:03 | Bangladesh | Steel work activity | 32 | 68.50 | 176.37 | 5 |
| | 2 | 09:08 | 01:51 | Egyptian | | 33 | 66.93 | 180.78 | 5 |
| | 3 | 09:13 | 01:46 | Indian | | 40 | 67.72 | 187.39 | 5 |
| | 4 | 09:16 | 01:44 | Pakistani | | 35 | 69.29 | 187.39 | 5 |
| | 5 | 09:21 | 01:42 | Nepalese | | 35 | 61.02 | 165.35 | 5 |
| Fifth Site Measurement | 1 | 17:29 | 03:26 | Pakistani | Steel fixer | 25 | 74.80 | 194.01 | 5 |
| | 2 | 17:37 | 03:18 | Indian | Tower Crane Deriver | 30 | 66.14 | 158.73 | 5 |
| | 3 | 17:42 | 03:18 | Bangladesh | Steel fixer | 33 | 66.93 | 167.55 | 5 |
| | 4 | 17:50 | 03:08 | Nepalese | Carpenter | 39 | 63.78 | 154.32 | 5 |
| | 5 | 17:56 | 03:03 | Nepalese | Carpenter | 35 | 67.72 | 178.57 | 5 |
| Sixth Site Measurement | 1 | 09:02 | 02:30 | Indian | Steel work activity | 24 | 66.93 | 165.35 | 5 |
| | 2 | 09:12 | 02:21 | Nepalese | | 41 | 67.72 | 176.37 | 5 |
| | 3 | 09:17 | 02:21 | Indian | | 46 | 67.72 | 143.30 | 5 |
| | 4 | 09:21 | 02:12 | Indian | | 37 | 62.20 | 121.25 | 5 |
| | 5 | 09:25 | 02:08 | Pakistani | | 32 | 66.54 | 149.91 | 5 |
| Seventh Site Measurement | 1 | 15:49 | 01:31 | Indian | Steel work activity | 33 | 74.41 | 187.39 | 5 |
| | 2 | 15:51 | 01:29 | Indian | Steel work activity | 37 | 65.75 | 160.94 | 5 |
| | 3 | 15:55 | 01:24 | Indian | Steel work activity | 36 | 69.69 | 176.37 | 5 |
| | 4 | 15:59 | 01:20 | Indian | Steel work activity | 28 | 66.93 | 196.21 | 5 |
| | 5 | 16:03 | 01:17 | Indian | Loader Deriver | 29 | 69.69 | 180.78 | 5 |

**Table C6: Weather conditions of the last four measurements (Source: weatherspark.com).**

| Fourth site measurements | | | Fifth site measurements | | | Sixth site measurements | | | Seventh site measurements | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | Temperature °C | Humidity % | Time | Temperature °C | Humidity % | Time | Temperature °C | Humidity % | Time | Temperature °C | Humidity % |
| 8:45 AM | 34 | 53 | 5:19 PM | 39.2 | 32 | 9:12 AM | 34.9 | 44 | 3:56 PM | 41 | 34 |
| 8:55 AM | 34.2 | 51 | 5:30 PM | 38.9 | 32 | 9:22 AM | 35.1 | 42 | 4:06 PM | 40.9 | 34 |
| 9:05 AM | 34.4 | 51 | 5:40 PM | 38.7 | 33 | 9:32 AM | 35.4 | 41 | 4:16 PM | 40.8 | 35 |
| 9:15 AM | 34.7 | 49 | 5:50 PM | 38.4 | 32 | 9:42 AM | 35.6 | 40 | 4:26 PM | 40.7 | 35 |
| 9:25 AM | 34.9 | 48 | 6:00 PM | 38.2 | 33 | 9:52 AM | 35.8 | 41 | 4:36 PM | 40.6 | 35 |
| 9:35 AM | 35.2 | 46 | 6:10 PM | 37.9 | 33 | 10:03 AM | 36.1 | 40 | 4:46 PM | 40.5 | 36 |
| 9:45 AM | 35.4 | 44 | 6:20 PM | 37.6 | 33 | 10:13 AM | 36.3 | 40 | 4:56 PM | 40.3 | 36 |
| 9:55 AM | 35.6 | 42 | 6:30 PM | 37.3 | 32 | 10:23 AM | 36.5 | 40 | 5:06 PM | 40.2 | 36 |
| 10:05 AM | 36 | 39 | 6:40 PM | 37 | 35 | 10:43 AM | 37 | 40 | 5:27 PM | 39.8 | 38 |
| 10:15 AM | 36.3 | 40 | 6:50 PM | 36.8 | 36 | 10:53 AM | 37.3 | 39 | | | |
| 10:26 AM | 36.6 | 38 | 7:00 PM | 36.6 | 36 | 11:03 AM | 37.5 | 39 | | | |
| 10:36 AM | 36.8 | 37 | 7:11 PM | 36.4 | 38 | 11:13 AM | 37.6 | 40 | | | |
| 10:46 AM | 37.2 | 36 | 7:21 PM | 36.2 | 37 | 11:23 AM | 37.9 | 37 | | | |
| 10:56 AM | 37.4 | 35 | 7:31 PM | 36.1 | 38 | 11:33 AM | 38.2 | 37 | | | |
| 11:06 AM | 37.7 | 35 | 7:51 PM | 35.8 | 40 | 11:43 AM | 38.4 | 36 | | | |
| 11:16 AM | 38 | 34 | 8:01 PM | 35.7 | 40 | 11:53 AM | 38.7 | 37 | | | |
| 11:26 AM | 38.3 | 30 | 8:11 PM | 35.5 | 40 | | | | | | |
| 11:36 AM | 38.6 | 31 | 8:21 PM | 35.4 | 40 | | | | | | |
| 11:46 AM | 38.8 | 33 | 8:31 PM | 35.3 | 40 | | | | | | |
| 11:56 AM | 39 | 33 | 8:41 PM | 35.2 | 40 | | | | | | |
| 12:07 PM | 39.2 | 32 | 8:52 PM | 35.1 | 42 | | | | | | |

## 2. Two-tailed Grubbs' test results

**Table C7: Two-tailed ("smallest and largest value is an outlier") HR Grubbs' test results of the 1st and 2nd site measurements.**

| Measurements | Subject # | Session # | P-Value | Decision | No. Outliers | From (min) | To (min) |
|---|---|---|---|---|---|---|---|
| First Construction Site Measurements | | Recording starts at (09:50:18 A.M.) / Recording Time (04:48:07) | | | | | |
| | 1 | 1 | 1.000 | None | 0 | 1 | 80.033 |
| | | 2 | 1.000 | None | 0 | 80.033 | 140.65 |
| | | 3 | 0.317 | None | 0 | 140.65 | 288.12 |
| | | Recording starts at (09:56:47 A.M.) / Recording Time (04:41:02) | | | | | |
| | 2 | 1 | 1.000 | None | 0 | 1 | 80.033 |
| | | 2 | 0.000 | Outliers | 8 | 80.033 | 140.65 |
| | | 3 | 1.000 | None | 0 | 140.65 | 288.12 |
| | | Recording starts at (10:01:01 A.M.) / Recording Time (02:57:14) | | | | | |
| | 3 | 1 | 0.979 | None | 0 | 1 | 80.033 |
| | | 2 | 1.000 | None | 0 | 80.033 | 140.65 |
| | | 3 | 0.003 | Outliers | 6 | 140.65 | 288.12 |
| | | Recording starts at (10:03:36 A.M.) / Recording Time (04:35:03) | | | | | |
| | 4 | 1 | 1.000 | None | 0 | 1 | 80.033 |
| | | 2 | 1.000 | None | 0 | 80.033 | 140.65 |
| | | 3 | 0.000 | Outliers | 2 | 140.65 | 288.12 |
| | | Recording starts at (10:05:46 A.M.) / Recording Time (04:33:11) | | | | | |
| | 5 | 1 | 1.000 | None | 0 | 1 | 80.033 |
| | | 2 | 1.000 | None | 0 | 80.033 | 140.65 |
| | | 3 | 1.000 | None | 0 | 140.65 | 288.12 |
| Second Construction Site Measurements | | Recording starts at (09:43:15 A.M.) / Recording Time (04:33:44) | | | | | |
| | 1 | 1 | 1.000 | None | 0 | 1 | 121.75 |
| | | 2 | 1.000 | None | 0 | 121.75 | 196.75 |
| | | 3 | 1.000 | None | 0 | 196.75 | 273.73 |
| | | Recording starts at (09:46:54 A.M.) / Recording Time (04:30:15) | | | | | |
| | 2 | 1 | 1.000 | None | 0 | 1 | 118.10 |
| | | 2 | 0.165 | None | 0 | 118.10 | 193.10 |
| | | 3 | 1.000 | None | 0 | 193.10 | 260.20 |
| | | Recording starts at (09:49:09 A.M.) / Recording Time (04:28:14) | | | | | |
| | 3 | 1 | 1.000 | None | 0 | 1 | 115.85 |
| | | 2 | 1.000 | None | 0 | 115.85 | 190.85 |
| | | 3 | 0.931 | None | 0 | 190.85 | 268.23 |
| | | Recording starts at (09:09:57 A.M.) / Recording Time (05:07:34) | | | | | |
| | 4 | 1 | 0.348 | None | 0 | 1 | 155.05 |
| | | 2 | 1.000 | None | 0 | 155.05 | 230.05 |
| | | 3 | 1.000 | None | 0 | 230.05 | 307.57 |
| | | Recording starts at (09:53:11 A.M.) / Recording Time (04:24:01) | | | | | |
| | 5 | 1 | 0.000 | Outliers | 32 | 1 | 111.82 |
| | | 2 | 1.000 | None | 0 | 111.82 | 186.82 |
| | | 3 | 1.000 | None | 0 | 186.82 | 264.02 |

**Table C8: Two-tailed ("smallest and largest value is an outlier") HR Grubbs' test results of the 3rd, 4th and 5th site measurements.**

| Measurements | Subject # | Session # | P-Value | Decision | No. Outliers | From (min) | To (min) |
|---|---|---|---|---|---|---|---|
| Third Construction Site Measurements | | Recording starts at (09:58:00 P.M.) / Recording Time (04:38:41) | | | | | |
| | 1 | 1 | 1.000 | None | 0 | 1 | 200 |
| | | 2 | 1.000 | None | 0 | 200 | 242 |
| | | 3 | 1.000 | None | 0 | 242 | 338.35 |
| | | Recording starts at (09:57:42 P.M.) / Recording Time (04:31:09) | | | | | |
| | 2 | 1 | 0.000 | Outliers | 87 | 1 | 140.30 |
| | | 2 | 0.149 | None | 0 | 140.30 | 182.30 |
| | | 3 | 1.000 | None | 0 | 182.30 | 268.15 |
| | | Recording starts at (09:57:51 P.M.) / Recording Time (04:28:48) | | | | | |
| | 3 | 1 | 0.002 | Outliers | 7 | 1 | 140.15 |
| | | 2 | 1.000 | None | 0 | 140.15 | 182.15 |
| | | 3 | 1.000 | None | 0 | 182.15 | 268.80 |
| | | Recording starts at (09:57:38 P.M.) / Recording Time (04:36:09) | | | | | |
| | 4 | 1 | 0.000 | Outliers | 29 | 1 | 140.37 |
| | | 2 | 1.000 | None | 0 | 140.37 | 182.37 |
| | | 3 | 0.017 | Outliers | 14 | 182.37 | 276.15 |
| | | Recording starts at (09:57:33 A.M.) / Recording Time (04:26:24) | | | | | |
| | 5 | 1 | 0.008 | Outliers | 89 | 1 | 140.45 |
| | | 2 | 1.000 | None | 0 | 140.45 | 182.45 |
| | | 3 | 0.000 | Outliers | 6 | 182.45 | 266.40 |
| Fourth Construction Site Measurements | | Recording starts at (09:02:56 A.M.) / Recording Time (02:03:43) | | | | | |
| | 1 | 1 | 0.000 | Outliers | 1 | 1.02 | 60.42 |
| | | 2 | 1.000 | None | 0 | 60.43 | 75.32 |
| | | 3 | 0.076 | None | 0 | 75.33 | 123.72 |
| | | Recording starts at (09:08:40 A.M.) / Recording Time (01:51:07) | | | | | |
| | 2 | 1 | 1.000 | None | 0 | 1 | 34.77 |
| | | 2 | 0.504 | None | 0 | 34.78 | 47.35 |
| | | 3 | 1.000 | None | 0 | 47.37 | 111 |
| | | Recording starts at (09:13:36 A.M.) / Recording Time (01:46:50) | | | | | |
| | 3 | 1 | 0.019 | Outliers | 1 | 1 | 73.87 |
| | | 2 | 0.027 | Outliers | 1 | 73.88 | 88.93 |
| | | 3 | 1.000 | None | 0 | 88.95 | 106.83 |
| | | Recording starts at (09:16:45 A.M.) / Recording Time (01:44:51) | | | | | |
| | 4 | 1 | 0.050 | None | 0 | 1 | 75.67 |
| | | 2 | 0.073 | None | 0 | 75.68 | 85.23 |
| | | 3 | 0.105 | None | 0 | 85.25 | 104.85 |
| | | Recording starts at (09:21:37 A.M.) / Recording Time (01:42:17) | | | | | |
| | 5 | 1 | 1.000 | None | 0 | 1 | 62.85 |
| | | 2 | 0.001 | Outliers | 3 | 62.87 | 71.68 |
| | | 3 | 0.026 | Outliers | 6 | 71.70 | 102.25 |
| Fifth Construction Site Measurements | | Recording starts at (17:29:40 A.M.) / Recording Time (03:26:50) | | | | | |
| | 1 | 1 | 1.000 | None | 0 | 1.02 | 53.58 |
| | | 2 | 1.000 | None | 0 | 53.60 | 68.00 |
| | | 3 | 1.000 | None | 0 | 68.02 | 206.57 |
| | | Recording starts at (17:37:16 A.M.) / Recording Time (03:18:32) | | | | | |
| | 2 | 1 | 1.000 | None | 0 | 1.00 | 45.97 |
| | | 2 | 0.211 | None | 0 | 45.98 | 60.97 |
| | | 3 | 1.000 | None | 0 | 60.98 | 198.53 |
| | | Recording starts at (17:42:21 A.M.) / Recording Time (03:18:08) | | | | | |
| | 3 | 1 | 1.000 | None | 0 | 1.00 | 40.25 |
| | | 2 | 1.000 | None | 0 | 40.27 | 58.10 |
| | | 3 | 1.000 | None | 0 | 58.12 | 198.13 |
| | | Recording starts at (17:50:54 A.M.) / Recording Time (03:08:01) | | | | | |
| | 4 | 1 | 1.000 | None | 0 | 1.00 | 32.08 |
| | | 2 | 1.000 | None | 0 | 32.10 | 47.08 |
| | | 3 | 1.000 | None | 0 | 47.10 | 188.02 |
| | | Recording starts at (17:56:05 A.M.) / Recording Time (17:56:05) | | | | | |
| | 5 | 1 | 1.000 | None | 0 | 1.00 | 26.95 |
| | | 2 | 0.450 | None | 0 | 26.97 | 41.98 |
| | | 3 | 1.000 | None | 0 | 42.00 | 183.35 |

**Table C9: Two-tailed (“smallest and largest value is an outlier”) HR Grubbs’ test results of the 6th and 7th site measurements.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sixth Construction Site Measurements | Recording starts at (09:02:55 A.M.) / Recording Time (02:30:10) | | | | | | |
| | 1 | 1 | 1.000 | None | 0 | 1.00 | 91.60 |
| | | 2 | 1.000 | None | 0 | 91.62 | 97.85 |
| | | 3 | 0.000 | Outliers | 2 | 97.87 | 150.17 |
| | Recording starts at (09:12:51 A.M.) / Recording Time (02:21:30) | | | | | | |
| | 2 | 1 | 0.041 | Outliers | 5 | 1.00 | 70.98 |
| | | 2 | 0.069 | None | 0 | 71.00 | 84.37 |
| | | 3 | 0.270 | None | 0 | 84.38 | 141.50 |
| | Recording starts at (09:17:00 A.M.) / Recording Time (02:21:46) | | | | | | |
| | 3 | 1 | 1.000 | None | 0 | 1.00 | 52.01 |
| | | 2 | 0.482 | None | 0 | 52.02 | 70.08 |
| | | 3 | 1.000 | None | 0 | 70.10 | 141.77 |
| | Recording starts at (09:21:31 A.M.) / Recording Time (02:12:08) | | | | | | |
| | 4 | 1 | 0.598 | None | 0 | 1.00 | 44.68 |
| | | 2 | 0.595 | None | 0 | 44.70 | 55.72 |
| | | 3 | 0.973 | None | 0 | 55.73 | 132.13 |
| | Recording starts at (09:25:08 A.M.) / Recording Time (02:08:36) | | | | | | |
| | 5 | 1 | 1.000 | None | 0 | 1.00 | 75.78 |
| | | 2 | 0.796 | None | 0 | 56.47 | 56.45 |
| | | 3 | 1.000 | None | 0 | 75.80 | 128.42 |
| Seventh Construction Site Measurements | Recording starts at (15:49:09 A.M.) / Recording Time (01:31:15) | | | | | | |
| | 1 | 1 | 0.782 | None | 0 | 1.00 | 44.77 |
| | | 2 | 0.003 | Outliers | 4 | 44.78 | 50.53 |
| | | 3 | 1.000 | None | 0 | 50.55 | 91.25 |
| | Recording starts at (15:51:41 A.M.) / Recording Time (01:29:00) | | | | | | |
| | 2 | 1 | 1.000 | None | 0 | 1.00 | 25.08 |
| | | 2 | 1.000 | None | 0 | 25.10 | 39.98 |
| | | 3 | 1.000 | None | 0 | 40.00 | 89.00 |
| | Recording starts at (15:55:28 A.M.) / Recording Time (01:24:38) | | | | | | |
| | 3 | 1 | 1.000 | None | 0 | 1.00 | 44.73 |
| | | 2 | 1.000 | None | 0 | 44.75 | 57.63 |
| | | 3 | 1.000 | None | 0 | 57.65 | 84.62 |
| | Recording starts at (15:59:05 A.M.) / Recording Time (01:20:46) | | | | | | |
| | 4 | 1 | 0.093 | None | 0 | 1.00 | 40.00 |
| | | 2 | 1.000 | None | 0 | 40.02 | 53.98 |
| | | 3 | 1.000 | None | 0 | 54.00 | 80.62 |
| | Recording starts at (16:03:10 A.M.) / Recording Time (01:17:58) | | | | | | |
| | 5 | 1 | 0.508 | None | 0 | 1.00 | 31.10 |
| | | 2 | 0.000 | Outliers | 7 | 31.12 | 42.82 |
| | | 3 | 1.000 | None | 0 | 42.83 | 77.97 |

## 3. Statistical summary of the recorded data

**Table C10: Statistical summary of the recorded data on 2015.**

| Measurements | Subject | Session | HR Max | HR Min | HR Avg. | HR SD | BMI | Fat% | Estimated $(HR_{max})$ | Measured/Predicted% Shift 1 | Measured/Predicted% Shift 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First Construction Site Measurement | 1 | 1 | 132 | 75 | 103.640 | 11.630 | 24.933 | 21.310 | 186.012 | 71% | 72% |
| | | 2 | 134 | 68 | 86.849 | 13.426 | | | | | |
| | | 3 | 134 | 52 | 98.549 | 11.263 | | | | | |
| | 2 | 1 | 154 | 71 | 108.64 | 13.1 | 28.006 | 25.228 | 185.471 | 83% | 75% |
| | | 2 | 126 | 62 | 85.396 | 9.468 | | | | | |
| | | 3 | 140 | 57 | 96.164 | 12.22 | | | | | |
| | 3 | 1 | 132 | 66 | 94.43 | 10.128 | 27.064 | 25.936 | 180.589 | 73% | 58% |
| | | 2 | 123 | 59 | 85.087 | 11.254 | | | | | |
| | | 3 | 105 | 53 | 67.881 | 8.953 | | | | | |
| | 4 | 1 | 151 | 79 | 116.33 | 11.87 | 29.071 | 24.895 | 188.959 | 80% | 71% |
| | | 2 | 141 | 81 | 105.3 | 12.56 | | | | | |
| | | 3 | 135 | 64 | 100.5 | 8.81 | | | | | |
| | 5 | 1 | 119 | 59 | 87.557 | 11.295 | 27.883 | 24.160 | 187.547 | 63% | 63% |
| | | 2 | 123 | 51 | 75.921 | 17.627 | | | | | |
| | | 3 | 118 | 50 | 79.837 | 12.407 | | | | | |
| Second Construction Site Measurement | 1 | 1 | 129 | 57 | 90.307 | 13.685 | 21.969 | 15.683 | 190.257 | 68% | 61% |
| | | 2 | 117 | 52 | 78.773 | 13.587 | | | | | |
| | | 3 | 117 | 60 | 89.974 | 9.952 | | | | | |
| | 2 | 1 | 125 | 69 | 99.673 | 9.199 | 31.105 | 29.406 | 184.346 | 68% | 62% |
| | | 2 | 121 | 73 | 93.71 | 6.617 | | | | | |
| | | 3 | 114 | 79 | 96.892 | 5.317 | | | | | |
| | 3 | 1 | 136 | 64 | 99.354 | 13.792 | 23.106 | 18.197 | 188.031 | 72% | 59% |
| | | 2 | 118 | 66 | 87.723 | 11.616 | | | | | |
| | | 3 | 111 | 68 | 87.343 | 6.367 | | | | | |
| | 4 | 1 | 212 | 24 | 103.47 | 26.52 | 17.838 | 13.716 | 183.760 | 115% | 64% |
| | | 2 | 132 | 72 | 95.041 | 12.118 | | | | | |
| | | 3 | 118 | 71 | 97.863 | 7.431 | | | | | |
| | 5 | 1 | 121 | 67 | 95.289 | 7.185 | 30.022 | 31.550 | 173.771 | 70% | 62% |
| | | 2 | 105 | 62 | 83.134 | 8.989 | | | | | |
| | | 3 | 107 | 66 | 86.86 | 6.248 | | | | | |
| Third Construction Site Measurement | 1 | 1 | 154 | 62 | 104.56 | 15.95 | 25.060 | 20.082 | 188.959 | 81% | 69% |
| | | 2 | 131 | 69 | 94.248 | 12.179 | | | | | |
| | | 3 | 130 | 70 | 93.374 | 11.953 | | | | | |
| | 2 | 1 | 122 | 59 | 89.504 | 7.338 | 26.489 | 24.556 | 182.541 | 67% | 64% |
| | | 2 | 114 | 67 | 81.479 | 8.11 | | | | | |
| | | 3 | 116 | 67 | 86.952 | 9.457 | | | | | |
| | 3 | 1 | 121 | 46 | 87.377 | 9.307 | 23.625 | 18.130 | 189.404 | 64% | 69% |
| | | 2 | 120 | 71 | 91.34 | 9.849 | | | | | |
| | | 3 | 131 | 65 | 92.207 | 11.01 | | | | | |
| | 4 | 1 | 143 | 36 | 90.457 | 12.189 | 20.663 | 14.115 | 190.257 | 75% | 79% |
| | | 2 | 114 | 64 | 83.137 | 9.537 | | | | | |
| | | 3 | 150 | 58 | 82.16 | 15.454 | | | | | |
| | 5 | 1 | 132 | 49 | 90.371 | 9.428 | 29.055 | 26.256 | 186.012 | 71% | 63% |
| | | 2 | 113 | 77 | 93.875 | 6.274 | | | | | |
| | | 3 | 117 | 67 | 95.318 | 6.749 | | | | | |

**Table C11: Statistical summary of the recorded data on 2016.**

| Measurements | Subject | Session | HR Max | HR Min | HR Avg. | HR SD | BMI | Fat% | Estimated ($HR_{max}$) | Measured/Predicted% Shift 1 | Measured/Predicted% Shift 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fourth Construction Site Measurement | 1 | 1 | 122 | 82 | 101.88 | 6.08 | | | | | |
| | | 2 | 107 | 87 | 96.29 | 3.364 | 26.427 | 22.9% | 186.537 | 65% | 70% |
| | | 3 | 131 | 82 | 101.45 | 7.04 | | | | | |
| | 2 | 1 | 168 | 92 | 126.76 | 14.39 | | | | | |
| | | 2 | 102 | 78 | 87.555 | 4.26 | 28.373 | 25.4% | 186.012 | 90% | 80% |
| | | 3 | 149 | 75 | 104 | 16.95 | | | | | |
| | 3 | 1 | 136 | 83 | 109.09 | 6.25 | | | | | |
| | | 2 | 116 | 93 | 101.79 | 3.55 | 28.728 | 27.5% | 181.907 | 75% | 73% |
| | | 3 | 133 | 98 | 119.94 | 6.95 | | | | | |
| | 4 | 1 | 117 | 52 | 93.703 | 9.514 | | | | | |
| | | 2 | 92 | 73 | 79.93 | 3.168 | 27.441 | 24.8% | 184.916 | 63% | 64% |
| | | 3 | 118 | 49 | 93.219 | 11.394 | | | | | |
| | 5 | 1 | 134 | 92 | 110.44 | 9.42 | | | | | |
| | | 2 | 107 | 91 | 96.878 | 2.935 | 31.222 | 29.3% | 184.916 | 72% | 64% |
| | | 3 | 119 | 81 | 93.921 | 6.189 | | | | | |
| Fifth Construction Site Measurement | 1 | 1 | 132 | 60 | 88.893 | 12.217 | | | | | |
| | | 2 | 131 | 73 | 104.12 | 11.13 | 24.379 | 18.8% | 189.836 | 70% | 74% |
| | | 3 | 141 | 57 | 92.839 | 13.511 | | | | | |
| | 2 | 1 | 126 | 74 | 98.648 | 8.554 | | | | | |
| | | 2 | 119 | 74 | 89.257 | 8.114 | 25.511 | 21.3% | 187.547 | 67% | 69% |
| | | 3 | 130 | 65 | 94.487 | 10.765 | | | | | |
| | 3 | 1 | 114 | 75 | 97.312 | 7.017 | | | | | |
| | | 2 | 121 | 69 | 92.509 | 11.567 | 26.297 | 22.9% | 186.012 | 61% | 77% |
| | | 3 | 144 | 72 | 102.14 | 12.33 | | | | | |
| | 4 | 1 | 120 | 70 | 93.006 | 11.703 | | | | | |
| | | 2 | 106 | 73 | 83.193 | 7.18 | 26.672 | 24.8% | 182.541 | 66% | 70% |
| | | 3 | 127 | 64 | 84.989 | 12.092 | | | | | |
| | 5 | 1 | 115 | 76 | 96.662 | 6.388 | | | | | |
| | | 2 | 118 | 79 | 95.116 | 6.594 | 27.376 | 24.7% | 184.916 | 62% | 68% |
| | | 3 | 126 | 65 | 91.58 | 8.945 | | | | | |
| Sixth Construction Site Measurement | 1 | 1 | 137 | 78 | 110.32 | 10.21 | | | | | |
| | | 2 | 120 | 78 | 99.195 | 8.805 | 25.951 | 20.5% | 190.257 | 72% | 67% |
| | | 3 | 127 | 77 | 104.3 | 7.41 | | | | | |
| | 2 | 1 | 130 | 70 | 91.939 | 8.76 | | | | | |
| | | 2 | 98 | 70 | 79.976 | 4.612 | 27.039 | 25.7% | 181.256 | 72% | 65% |
| | | 3 | 117 | 64 | 84.428 | 8.259 | | | | | |
| | 3 | 1 | 125 | 81 | 101.03 | 9.48 | | | | | |
| | | 2 | 102 | 81 | 90.529 | 3.275 | 21.969 | 20.7% | 177.743 | 70% | 62% |
| | | 3 | 111 | 70 | 84.54 | 7.771 | | | | | |
| | 4 | 1 | 115 | 68 | 90.238 | 6.727 | | | | | |
| | | 2 | 102 | 75 | 85.414 | 5.014 | 22.034 | 18.8% | 183.760 | 63% | 61% |
| | | 3 | 112 | 71 | 87.835 | 6.529 | | | | | |
| | 5 | 1 | 125 | 81 | 101.03 | 9.48 | | | | | |
| | | 2 | 94 | 67 | 77.618 | 4.836 | 23.805 | 19.7% | 186.537 | 67% | 72% |
| | | 3 | 134 | 63 | 85.058 | 14.451 | | | | | |

**Table C11: Statistical summary of the recorded data on 2016.**

| Measurements | Subject | Session | HR | | | | BMI | Fat% | Estimated ($HR_{max}$) | Measured/ Predicted% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Max | Min | Avg. | SD | | | | Shift 1 | Shift 3 |
| Seventh Construction Site Measurement | 1 | 1 | 122 | 74 | 101.110 | 7.500 | 23.795 | 19.9% | 186.012 | 66% | 62% |
| | | 2 | 101 | 77 | 87.723 | 4.230 | | | | | |
| | | 3 | 115 | 74 | 91.856 | 7.268 | | | | | |
| | 2 | 1 | 166 | 84 | 118.66 | 17.24 | 26.174 | 23.7% | 183.760 | 90% | 72% |
| | | 2 | 98 | 67 | 81.054 | 5.22 | | | | | |
| | | 3 | 133 | 77 | 105.11 | 11.06 | | | | | |
| | 3 | 1 | 144 | 96 | 120.86 | 9.24 | 25.532 | 22.7% | 184.346 | 78% | 68% |
| | | 2 | 115 | 97 | 104.22 | 3.39 | | | | | |
| | | 3 | 126 | 91 | 108.75 | 5.88 | | | | | |
| | 4 | 1 | 146 | 70 | 123.4 | 13.02 | 30.795 | 27.2% | 188.501 | 77% | 63% |
| | | 2 | 120 | 76 | 97.213 | 7.794 | | | | | |
| | | 3 | 119 | 69 | 93.22 | 9.067 | | | | | |
| | 5 | 1 | 132 | 81 | 102.52 | 8.13 | 26.170 | 21.9% | 188.031 | 70% | 72% |
| | | 2 | 118 | 86 | 99.193 | 4.841 | | | | | |
| | | 3 | 136 | 92 | 111.65 | 8.81 | | | | | |

## 4. HR acceptable ranges and zones

**Table C12: HR acceptable ranges and zones for the site measurements.**

| Measurem | Subject | Session | Max. Acceptable HR | HR zones (bpm) | | THR |
|---|---|---|---|---|---|---|
| | | | $HR_{max}$ | $HR_L$ | $HR_U$ | |
| Site Measurement 1 | 1 | 1 | 155.260 | 120.356 | 129.082 | 125.249 |
| | | 3 | 156.526 | 121.116 | 129.968 | 126.449 |
| | 2 | 1 | 180.200 | 132.920 | 144.740 | 140.596 |
| | | 3 | 164.44 | 123.464 | 133.708 | 132.196 |
| | 3 | 1 | 152.256 | 114.954 | 124.279 | 128.887 |
| | | 3 | 122.906 | 97.344 | 103.734 | 112.687 |
| | 4 | 1 | 174.740 | 137.244 | 146.618 | 147.300 |
| | | 3 | 152.62 | 123.972 | 131.134 | 137.700 |
| | 5 | 1 | 141.590 | 105.354 | 114.413 | 116.721 |
| | | 3 | 142.814 | 106.088 | 115.270 | 116.121 |
| Site Measurement 2 | 1 | 1 | 156.370 | 114.622 | 125.059 | 124.973 |
| | | 3 | 136.904 | 102.942 | 111.433 | 117.773 |
| | 2 | 1 | 143.398 | 115.239 | 122.279 | 124.910 |
| | | 3 | 124.634 | 103.980 | 109.144 | 118.310 |
| | 3 | 1 | 163.584 | 124.550 | 134.309 | 129.723 |
| | | 3 | 123.734 | 100.640 | 106.414 | 114.723 |
| | 4 | 1 | 265.040 | 187.824 | 207.128 | 179.041 |
| | | 3 | 132.862 | 108.517 | 114.603 | 122.641 |
| | 5 | 1 | 135.370 | 106.022 | 113.359 | 118.534 |
| | | 3 | 119.496 | 96.498 | 102.247 | 110.134 |
| Site Measurement 3 | 1 | 1 | 185.900 | 139.140 | 150.83 | 145.248 |
| | | 3 | 153.906 | 119.944 | 128.434 | 130.848 |
| | 2 | 1 | 136.676 | 108.806 | 115.773 | 114.479 |
| | | 3 | 134.914 | 107.748 | 114.540 | 110.879 |
| | 3 | 1 | 139.614 | 112.168 | 119.030 | 121.340 |
| | | 3 | 153.02 | 120.212 | 128.414 | 127.340 |
| | 4 | 1 | 167.378 | 126.027 | 136.365 | 130.537 |
| | | 3 | 180.908 | 134.145 | 145.836 | 134.737 |
| | 5 | 1 | 150.856 | 121.314 | 128.699 | 126.875 |
| | | 3 | 130.498 | 109.099 | 114.449 | 117.875 |
| Site Measurement 4 | 1 | 1 | 134.160 | 115.296 | 120.012 | 117.290 |
| | | 3 | 145.080 | 121.848 | 127.656 | 122.690 |
| | 2 | 1 | 196.780 | 149.268 | 161.146 | 141.555 |
| | | 3 | 182.900 | 140.940 | 151.430 | 130.155 |
| | 3 | 1 | 148.500 | 126.300 | 131.850 | 127.590 |
| | | 3 | 146.900 | 125.340 | 130.730 | 125.790 |
| | 4 | 1 | 136.028 | 110.817 | 117.120 | 106.330 |
| | | 3 | 140.788 | 113.673 | 120.452 | 106.930 |
| | 5 | 1 | 152.840 | 128.104 | 134.288 | 122.678 |
| | | 3 | 131.378 | 115.227 | 119.265 | 113.678 |

**Table C12: HR acceptable ranges and zones for the site measurements.**

| Measurement | Subject | Session | Max. Acceptable HR | HR zones (bpm) | | THR |
|---|---|---|---|---|---|---|
| | | | $HR_{max}$ | $HR_L$ | $HR_U$ | |
| Site Measurement 5 | 1 | 1 | 156.434 | 114.660 | 131.404 | 123.290 |
| | | 3 | 168.022 | 130.013 | 139.515 | 128.690 |
| | 2 | 1 | 143.108 | 115.465 | 122.376 | 120.457 |
| | | 3 | 151.530 | 120.518 | 128.271 | 122.857 |
| | 3 | 1 | 128.034 | 104.420 | 110.324 | 119.509 |
| | | 3 | 168.660 | 128.796 | 138.762 | 137.509 |
| | 4 | 1 | 143.406 | 115.244 | 122.284 | 111.393 |
| | | 3 | 151.184 | 119.910 | 127.729 | 115.593 |
| | 5 | 1 | 127.776 | 108.266 | 113.143 | 116.716 |
| | | 3 | 143.890 | 117.934 | 124.423 | 123.316 |
| Site Measurement 6 | 1 | 1 | 143.890 | 117.934 | 124.423 | 123.316 |
| | | 3 | 157.420 | 120.252 | 133.594 | 126.290 |
| | 2 | 1 | 141.820 | 116.292 | 122.674 | 120.290 |
| | | 3 | 147.520 | 116.512 | 124.264 | 115.976 |
| | 3 | 1 | 133.518 | 108.111 | 114.463 | 108.176 |
| | | 3 | 143.960 | 118.776 | 125.072 | 116.929 |
| | 4 | 1 | 126.542 | 108.325 | 112.879 | 108.529 |
| | | 3 | 128.454 | 107.072 | 112.418 | 109.414 |
| | 5 | 1 | 143.960 | 113.176 | 120.872 | 112.418 |
| | | 3 | 162.902 | 124.541 | 134.131 | 117.818 |
| Site Measurement 7 | 1 | 1 | 137.000 | 107.000 | 119.000 | 117.290 |
| | | 3 | 129.536 | 108.522 | 113.775 | 113.090 |
| | 2 | 1 | 200.480 | 147.088 | 160.436 | 140.454 |
| | | 3 | 155.120 | 119.872 | 128.684 | 120.654 |
| | 3 | 1 | 162.480 | 136.288 | 142.836 | 132.420 |
| | | 3 | 137.760 | 121.456 | 125.532 | 121.620 |
| | 4 | 1 | 172.040 | 133.624 | 143.228 | 139.213 |
| | | 3 | 137.134 | 112.680 | 118.794 | 123.013 |
| | 5 | 1 | 148.260 | 123.356 | 129.582 | 126.793 |
| | | 3 | 153.620 | 126.572 | 133.334 | 129.193 |

## 5. Percentage of records exceeding physiological thresholds

**Table C13: Percentage of records exceeding physiological thresholds for the measurements of 2015.**

| Measurement | Subject | Session | % Exceeding HR Ranges | % Exceeding HR Zones |
|---|---|---|---|---|
| Site Measurement 1 | 1 | 1 | 0 | 0.300 |
| | | 3 | 0 | 0.360 |
| | 2 | 1 | 0 | 0.000 |
| | | 3 | 0 | 0.140 |
| | 3 | 1 | 0 | 0.550 |
| | | 3 | 0 | 0.500 |
| | 4 | 1 | 0 | 0.590 |
| | | 3 | 0 | 0.140 |
| | 5 | 1 | 0 | 0.650 |
| | | 3 | 0 | 0.080 |
| Site Measurement 2 | 1 | 1 | 0 | 0.193 |
| | | 3 | 0 | 0.445 |
| | 2 | 1 | 0 | 0.242 |
| | | 3 | 0 | 0.648 |
| | 3 | 1 | 0 | 0.377 |
| | | 3 | 0 | 0.409 |
| | 4 | 1 | 0 | 0.915 |
| | | 3 | 0 | 0.107 |
| | 5 | 1 | 1.038 | 2.212 |
| | | 3 | 0 | 0.173 |
| Site Measurement 3 | 1 | 1 | 0 | 0.057 |
| | | 3 | 0 | 0.636 |
| | 2 | 1 | 2.664 | 3.161 |
| | | 3 | 0 | 0.188 |
| | 3 | 1 | 0 | 0.013 |
| | | 3 | 0 | 0.442 |
| | 4 | 1 | 0.385 | 0.796 |
| | | 3 | 0 | 1.493 |
| | 5 | 1 | 4.314 | 4.583 |
| | | 3 | 0 | 0.238 |

**Table C14: Percentage of records exceeding physiological thresholds for the measurements of 2016.**

| Measurement | Subject | Session | % Exceeding HR Ranges | % Exceeding HR Zones |
|---|---|---|---|---|
| Site Measurement 4 | 1 | 1 | 0 | 0.393 |
| | | 3 | 0 | 0.207 |
| | 2 | 1 | 0 | 0.641 |
| | | 3 | 0 | 0 |
| | 3 | 1 | 0 | 0.527 |
| | | 3 | 0 | 1.583 |
| | 4 | 1 | 0 | 0 |
| | | 3 | 0 | 0 |
| | 5 | 1 | 0 | 0 |
| | | 3 | 0 | 0 |
| Site Measurement 5 | 1 | 1 | 0 | 0.158 |
| | | 3 | 0 | 0.024 |
| | 2 | 1 | 0 | 0.482 |
| | | 3 | 0 | 0.061 |
| | 3 | 1 | 0 | 1.528 |
| | | 3 | 0 | 0.428 |
| | 4 | 1 | 0 | 0 |
| | | 3 | 0 | 0 |
| | 5 | 1 | 0 | 0.128 |
| | | 3 | 0 | 0.047 |
| Site Measurement 6 | 1 | 1 | 0 | 7.467 |
| | | 3 | 0 | 0 |
| | 2 | 1 | 0 | 0.575 |
| | | 3 | 0 | 0 |
| | 3 | 1 | 0 | 13.198 |
| | | 3 | 0 | 0 |
| | 4 | 1 | 0 | 0.267 |
| | | 3 | 0 | 0 |
| | 5 | 1 | 2.073% | 43.239 |
| | | 3 | 0 | 0 |
| Site Measurement 7 | 1 | 1 | 0 | 0.495 |
| | | 3 | 0 | 0.409 |
| | 2 | 1 | 0 | 1.452 |
| | | 3 | 0 | 0.476 |
| | 3 | 1 | 0 | 0.267 |
| | | 3 | 0 | 0.185 |
| | 4 | 1 | 0 | 0.726 |
| | | 3 | 0 | 0.188 |
| | 5 | 1 | 0 | 0.387 |
| | | 3 | 0 | 0.664 |

## 6. Actual and expected maximum oxygen uptake level and metabolic equivalents (METs)

**Table C15: Actual and expected maximum oxygen uptake level and metabolic equivalents (METs) of site measurements (2015).**

| | Subje | Sessio n | $HR_{\min}$ at rest | $Avg.$ $HR_{rest}$ | $HR_{max}$ | $VO_{2_{max}}$ | METs | $VO_{2_{max}}^{*}$ | METs* |
|---|---|---|---|---|---|---|---|---|---|
| Site Measurement 1 | 1 | 1 | 68.000 | 86.849 | 132.000 | 29.118 | 8.319 | 22.798 | 6.514 |
| | | 3 | | | 134.000 | 29.559 | 8.445 | 23.144 | 6.612 |
| | 2 | 1 | 62.000 | 85.396 | 154.000 | 37.258 | 10.645 | 27.050 | 7.729 |
| | | 3 | | | 140.000 | 33.871 | 9.677 | 24.591 | 7.026 |
| | 3 | 1 | 59.000 | 85.087 | 132.000 | 33.559 | 9.588 | 23.270 | 6.649 |
| | | 3 | | | 105.000 | 26.695 | 7.627 | 18.510 | 5.289 |
| | 4 | 1 | 81.000 | 105.300 | 151.000 | 27.963 | 7.989 | 21.510 | 6.146 |
| | | 3 | | | 135.000 | 25.000 | 7.143 | 19.231 | 5.495 |
| | 5 | 1 | 51.000 | 75.921 | 119.000 | 35.000 | 10.000 | 23.511 | 6.718 |
| | | 3 | | | 118.000 | 34.706 | 9.916 | 23.314 | 6.661 |
| Site Measurement 2 | 1 | 1 | 52.000 | 78.773 | 129.000 | 37.212 | 10.632 | 24.564 | 7.018 |
| | | 3 | | | 117.000 | 33.750 | 9.643 | 22.279 | 6.365 |
| | 2 | 1 | 73.000 | 93.710 | 125.000 | 25.685 | 7.339 | 20.009 | 5.717 |
| | | 3 | | | 114.000 | 23.425 | 6.693 | 18.248 | 5.214 |
| | 3 | 1 | 66.000 | 87.723 | 136.000 | 30.909 | 8.831 | 23.255 | 6.644 |
| | | 3 | | | 111.000 | 25.227 | 7.208 | 18.980 | 5.423 |
| | 4 | 1 | 72.000 | 95.041 | 212.000 | 44.167 | 12.619 | 33.459 | 9.560 |
| | | 3 | | | 118.000 | 24.583 | 7.024 | 18.624 | 5.321 |
| | 5 | 1 | 62.000 | 83.134 | 121.000 | 29.274 | 8.364 | 21.832 | 6.238 |
| | | 3 | | | 107.000 | 25.887 | 7.396 | 19.306 | 5.516 |
| Site Measurement 3 | 1 | 1 | 69.000 | 94.248 | 154.000 | 33.478 | 9.565 | 24.510 | 7.003 |
| | | 3 | | | 130.000 | 28.261 | 8.075 | 20.690 | 5.911 |
| | 2 | 1 | 67.000 | 81.479 | 122.000 | 27.313 | 7.804 | 22.460 | 6.417 |
| | | 3 | | | 116.000 | 25.970 | 7.420 | 21.355 | 6.101 |
| | 3 | 1 | 71.000 | 91.340 | 121.000 | 25.563 | 7.304 | 19.871 | 5.677 |
| | | 3 | | | 131.000 | 27.676 | 7.907 | 21.513 | 6.147 |
| | 4 | 1 | 64.000 | 83.137 | 143.000 | 33.516 | 9.576 | 25.801 | 7.372 |
| | | 3 | | | 150.000 | 35.156 | 10.045 | 27.064 | 7.733 |
| | 5 | 1 | 77.000 | 93.875 | 132.000 | 25.714 | 7.347 | 21.092 | 6.026 |
| | | 3 | | | 117.000 | 22.792 | 6.512 | 18.695 | 5.341 |

**Table C16: Actual and expected maximum oxygen uptake level and metabolic equivalents (METs) of site measurements (2016).**

| Measurement | Subject | Session | $HR_{\min}$ at rest | $Avg.\ HR_{rest}$ | $HR_{max}$ | $VO_{2_{max}}$ | METs | $VO_{2_{max}}^{*}$ | METs* |
|---|---|---|---|---|---|---|---|---|---|
| Site Measurement 4 | 1 | 1 | 87 | 96.29 | 122 | 21.034 | 6.010 | 19.005 | 5.430 |
| | | 3 | | | 131 | 22.586 | 6.453 | 20.407 | 5.831 |
| | 2 | 1 | 78 | 87.555 | 168 | 32.308 | 9.231 | 28.782 | 8.223 |
| | | 3 | | | 149 | 28.654 | 8.187 | 25.527 | 7.293 |
| | 3 | 1 | 93 | 101.79 | 136 | 21.935 | 6.267 | 20.041 | 5.726 |
| | | 3 | | | 133 | 21.452 | 6.129 | 19.599 | 5.600 |
| | 4 | 1 | 73 | 79.93 | 117 | 24.041 | 6.869 | 21.957 | 6.273 |
| | | 3 | | | 118 | 24.247 | 6.928 | 22.144 | 6.327 |
| | 5 | 1 | 91 | 96.878 | 134 | 22.088 | 6.311 | 20.748 | 5.928 |
| | | 3 | | | 119 | 19.615 | 5.604 | 18.425 | 5.264 |
| Site Measurement 5 | 1 | 1 | 73 | 104.12 | 132 | 27.123 | 7.750 | 19.017 | 5.433 |
| | | 3 | | | 141 | 28.973 | 8.278 | 20.313 | 5.804 |
| | 2 | 1 | 74 | 89.257 | 126 | 25.541 | 7.297 | 21.175 | 6.050 |
| | | 3 | | | 130 | 26.351 | 7.529 | 21.847 | 6.242 |
| | 3 | 1 | 69 | 92.509 | 114 | 24.783 | 7.081 | 18.485 | 5.281 |
| | | 3 | | | 144 | 31.304 | 8.944 | 23.349 | 6.671 |
| | 4 | 1 | 73 | 83.193 | 120 | 24.658 | 7.045 | 21.636 | 6.182 |
| | | 3 | | | 127 | 26.096 | 7.456 | 22.899 | 6.542 |
| | 5 | 1 | 79 | 95.116 | 115 | 21.835 | 6.239 | 18.136 | 5.182 |
| | | 3 | | | 126 | 23.924 | 6.835 | 19.870 | 5.677 |
| Site Measurement 6 | 1 | 1 | 78 | 99.195 | 137 | 26.346 | 7.527 | 20.717 | 5.919 |
| | | 3 | | | 127 | 24.423 | 6.978 | 19.205 | 5.487 |
| | 2 | 1 | 70 | 79.976 | 130 | 27.857 | 7.959 | 24.382 | 6.966 |
| | | 3 | | | 117 | 25.071 | 7.163 | 21.944 | 6.270 |
| | 3 | 1 | 81 | 90.529 | 125 | 23.148 | 6.614 | 20.712 | 5.918 |
| | | 3 | | | 111 | 20.556 | 5.873 | 18.392 | 5.255 |
| | 4 | 1 | 75 | 85.414 | 115 | 23.000 | 6.571 | 20.196 | 5.770 |
| | | 3 | | | 112 | 22.400 | 6.400 | 19.669 | 5.620 |
| | 5 | 1 | 67 | 77.618 | 125 | 27.985 | 7.996 | 24.157 | 6.902 |
| | | 3 | | | 134 | 30.000 | 8.571 | 25.896 | 7.399 |
| Site Measurement 7 | 1 | 1 | 77 | 87.723 | 122 | 23.766 | 6.790 | 20.861 | 5.960 |
| | | 3 | | | 115 | 22.403 | 6.401 | 19.664 | 5.618 |
| | 2 | 1 | 67 | 81.054 | 166 | 37.164 | 10.618 | 30.720 | 8.777 |
| | | 3 | | | 133 | 29.776 | 8.507 | 24.613 | 7.032 |
| | 3 | 1 | 97 | 104.22 | 144 | 22.268 | 6.362 | 20.725 | 5.922 |
| | | 3 | | | 126 | 19.485 | 5.567 | 18.135 | 5.181 |
| | 4 | 1 | 76 | 97.213 | 146 | 28.816 | 8.233 | 22.528 | 6.437 |
| | | 3 | | | 119 | 23.487 | 6.711 | 18.362 | 5.246 |
| | 5 | 1 | 86 | 99.193 | 132 | 23.023 | 6.578 | 19.961 | 5.703 |
| | | 3 | | | 136 | 23.721 | 6.777 | 20.566 | 5.876 |

## 7. Actual and calculated activity intensity

**Table C17: Actual and calculated activity intensity of construction site measurements (2015).**

| Site Measurements of 2015 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Measurement | Subject | Session | Calculated Zone | | | Calculated Zone* | | |
| Site Measurement 1 | 1 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 2 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | 3 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 4 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 5 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| Site Measurement 2 | 1 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | 2 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 3 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 4 | 1 | 5 | ] 90:100%] | High | 5 | ] 90:100%] | High |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 5 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| Site Measurement 3 | 1 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 2 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 3 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 4 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | 5 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |

**Table C18: Actual and calculated activity intensity of construction site measurements (2016).**

| Site Measurements of 2016 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Measurement | Subject | Session | Calculated Zone | | | Calculated Zone* | | |
| Site Measurement 4 | 1 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 2 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 3 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 4 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 5 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 3 | ] 70:80%] | Moderate | 3 | ] 70:80%] | Moderate |
| Site Measurement 5 | 1 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 2 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 3 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 4 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 5 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| Site Measurement 6 | 1 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 2 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 3 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 3 | ] 70:80%] | Moderate | 3 | ] 70:80%] | Moderate |
| | 4 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 5 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| Site Measurement 7 | 1 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 2 | 1 | 5 | ] 90:100%] | High | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | 3 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 3 | ] 70:80%] | Moderate | 3 | ] 70:80%] | Moderate |
| | 4 | 1 | 4 | ] 80:90%] | Vigorous | 4 | ] 80:90%] | Vigorous |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | 5 | 1 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |
| | | 3 | 4 | ] 80:90%] | Vigorous | 3 | ] 70:80%] | Moderate |

## 8. A sample of HR and BR five minutes' summary.

**Table C19: HR and BR five minutes' summary for subject 1 of the first measurements of 2015.**

| Time | Time (min) | Temperature | Humidity | Avg. HR | Avg. BR | Session |
|---|---|---|---|---|---|---|
| 9:55:00 AM | 595.00 | 40.83 | 9.92 | 96.913 | 12.519 | First Session Start |
| 10:00:00 AM | 600.00 | 41 | 10 | 87.744 | 10.333 | |
| 10:05:00 AM | 605.00 | 41.17 | 9.83 | 93.591 | 8.8718 | |
| 10:10:00 AM | 610.00 | 41.33 | 9.67 | 91.591 | 10.609 | |
| 10:15:00 AM | 615.00 | 41.50 | 9.50 | 100.47 | 14.706 | |
| 10:20:00 AM | 620.00 | 41.67 | 9.33 | 102.56 | 13.094 | |
| 10:25:00 AM | 625.00 | 41.83 | 9.17 | 99.522 | 10.403 | |
| 10:30:00 AM | 630.00 | 42.00 | 9.00 | 103.99 | 9.8801 | |
| 10:35:00 AM | 635.00 | 42.17 | 8.83 | 105.79 | 9.7847 | |
| 10:40:00 AM | 640.00 | 42.33 | 8.67 | 112.18 | 16.016 | |
| 10:45:00 AM | 645.00 | 42.50 | 8.50 | 112.45 | 14.446 | |
| 10:50:00 AM | 650.00 | 42.67 | 8.33 | 114.14 | 20.537 | |
| 10:55:00 AM | 655.00 | 42.83 | 8.17 | 110.27 | 12.063 | |
| 11:00:00 AM | 660.00 | 43 | 8 | 108.02 | 13.38 | |
| 11:05:00 AM | 665.00 | 42.08 | 8.67 | 103 | 13.655 | |
| 11:10:00 AM | 670.00 | 41.17 | 9.33 | 114.83 | 24.694 | First Session End |
| 11:15:00 AM | 675.00 | 40.25 | 10.00 | 87.237 | 13.337 | Resting Session Start |
| 11:20:00 AM | 680.00 | 39.33 | 10.67 | 82.718 | 17.687 | |
| 11:25:00 AM | 685.00 | 38.42 | 11.33 | 80.502 | 76.647 | |
| 11:30:00 AM | 690.00 | 37.50 | 12.00 | 80.515 | 78.948 | |
| 11:35:00 AM | 695.00 | 36.58 | 12.67 | 83.508 | 50.599 | |
| 11:40:00 AM | 700.00 | 35.67 | 13.33 | 76.914 | 12.257 | |
| 11:45:00 AM | 705.00 | 34.75 | 14.00 | 96.698 | 12.641 | |
| 11:50:00 AM | 710.00 | 33.83 | 14.67 | 108.5 | 19.002 | |
| 11:55:00 AM | 715.00 | 32.92 | 15.33 | 102.94 | 16.742 | |
| 12:00:00 PM | 720.00 | 32 | 16 | 82.425 | 9.4389 | |
| 12:05:00 PM | 725.00 | 33.00 | 15.25 | 79.887 | 11.887 | |
| 12:10:00 PM | 730.00 | 34.00 | 14.50 | 81.196 | 11.541 | |
| 12:15:00 PM | 735.00 | 35.00 | 13.75 | 99.432 | 12.459 | Resting Session End |
| 12:20:00 PM | 740.00 | 36.00 | 13.00 | 90.781 | 7.7654 | Second Session Start |
| 12:25:00 PM | 745.00 | 37.00 | 12.25 | 88.638 | 10.719 | |
| 12:30:00 PM | 750.00 | 38.00 | 11.50 | 94.123 | 10.27 | |
| 12:35:00 PM | 755.00 | 39.00 | 10.75 | 90.621 | 15.656 | |
| 12:40:00 PM | 760.00 | 40.00 | 10.00 | 108.37 | 19.472 | |
| 12:45:00 PM | 765.00 | 41.00 | 9.25 | 107.96 | 18.527 | |
| 12:50:00 PM | 770.00 | 42.00 | 8.50 | 101.58 | 16.143 | |
| 12:55:00 PM | 775.00 | 43.00 | 7.75 | 94.595 | 8.7784 | |
| 1:00:00 PM | 780.00 | 44 | 7 | 103.67 | 15.41 | |
| 1:05:00 PM | 785.00 | 43.92 | 7.08 | 94.764 | 12.789 | |
| 1:10:00 PM | 790.00 | 43.83 | 7.17 | 99.429 | 13.747 | |
| 1:15:00 PM | 795.00 | 43.75 | 7.25 | 96.664 | 10.827 | |
| 1:20:00 PM | 800.00 | 43.67 | 7.33 | 97.904 | 8.0525 | |
| 1:25:00 PM | 805.00 | 43.58 | 7.42 | 95.963 | 11.831 | |
| 1:30:00 PM | 810.00 | 43.50 | 7.50 | 96.953 | 8.6286 | |
| 1:35:00 PM | 815.00 | 43.42 | 7.58 | 94.973 | 9.0272 | |
| 1:40:00 PM | 820.00 | 43.33 | 7.67 | 97.083 | 10.617 | |
| 1:45:00 PM | 825.00 | 43.25 | 7.75 | 86.757 | 11.986 | |
| 1:50:00 PM | 830.00 | 43.17 | 7.83 | 96.645 | 7.5445 | |
| 1:55:00 PM | 835.00 | 43.08 | 7.92 | 97.103 | 6.3286 | |
| 2:00:00 PM | 840.00 | 43.00 | 8.00 | 95.97 | 7.2286 | |
| 2:05:00 PM | 845.00 | 42.92 | 8.25 | 90.532 | 10.08 | |
| 2:10:00 PM | 850.00 | 42.83 | 8.50 | 96.346 | 17.384 | |
| 2:15:00 PM | 855.00 | 42.75 | 8.75 | 105.18 | 14.009 | |
| 2:20:00 PM | 860.00 | 42.67 | 9.00 | 104.77 | 14.366 | |
| 2:25:00 PM | 865.00 | 42.58 | 9.25 | 107.95 | 14.535 | |
| 2:30:00 PM | 870.00 | 42.50 | 9.50 | 107.72 | 13.184 | |
| 2:35:00 PM | 875.00 | 42.42 | 9.75 | 106.15 | 12.134 | |
| 2:40:00 PM | 880.00 | 42.33 | 10.00 | 107.9 | 17.637 | Third Session End |

## Appendix-D: Distribution Plot of the Recorded HR Data.

This section of the appendixes includes the distribution plot of participants recorded HR data.

### 1. First Construction Site Measurements

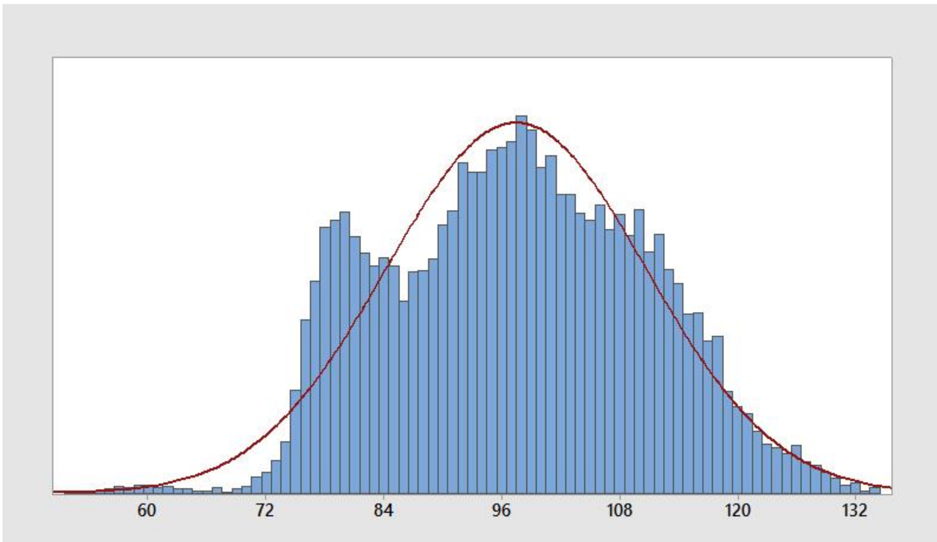


**Figure D1: Distribution plot for subject 1 of the first site measurements.**

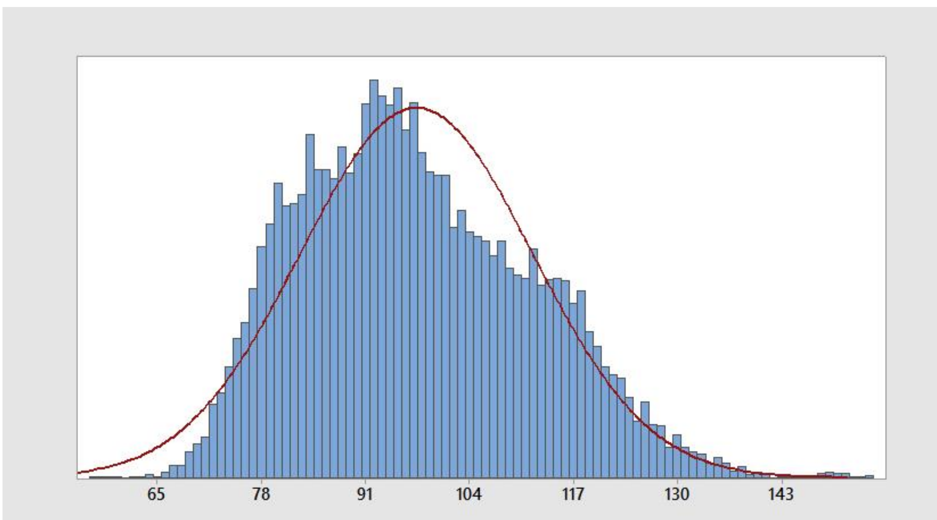


**Figure D2: Distribution plot for subject 2 of the first site measurements.**

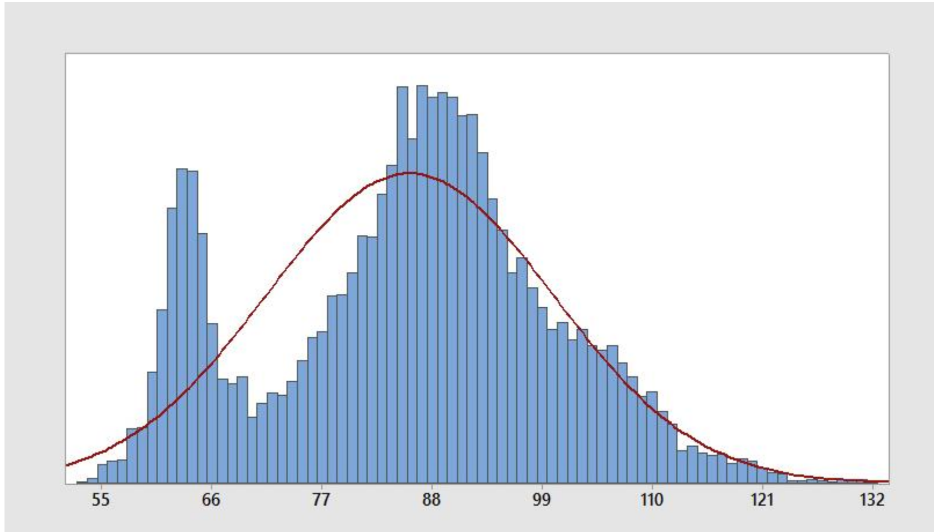


**Figure D3: Distribution plot for subject 3 of the first site measurements.**

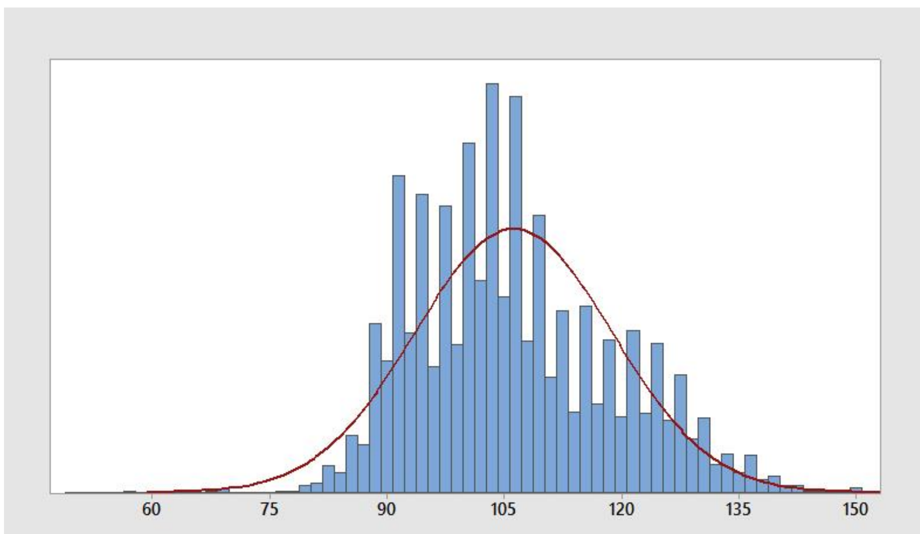


**Figure D4: Distribution plot for subject 4 of the first site measurements.**

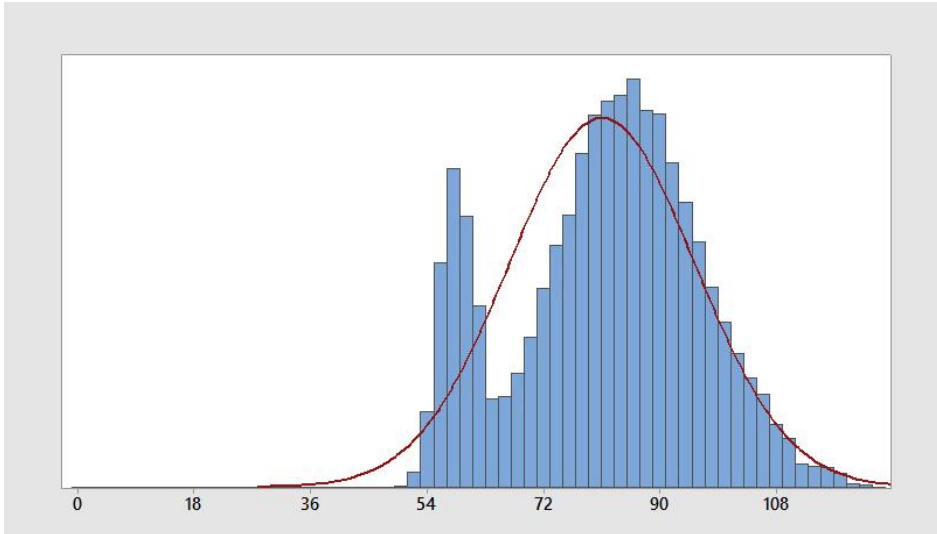


**Figure D5: Distribution plot for subject 5 of the first site measurements.**

## 2. Second Construction Site Measurements

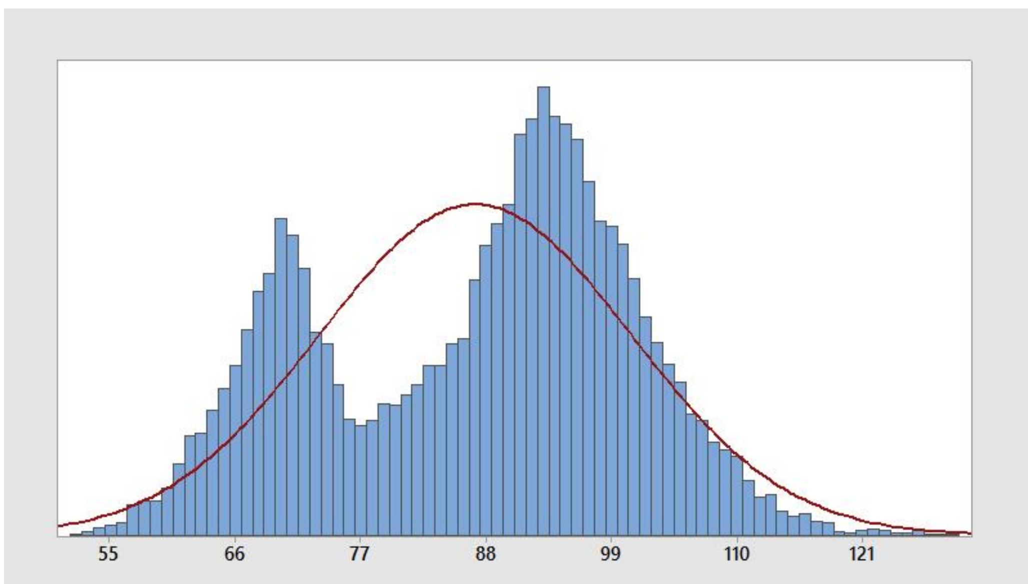


**Figure D6:Distribution plot for subject 1 of the second site measurements.**

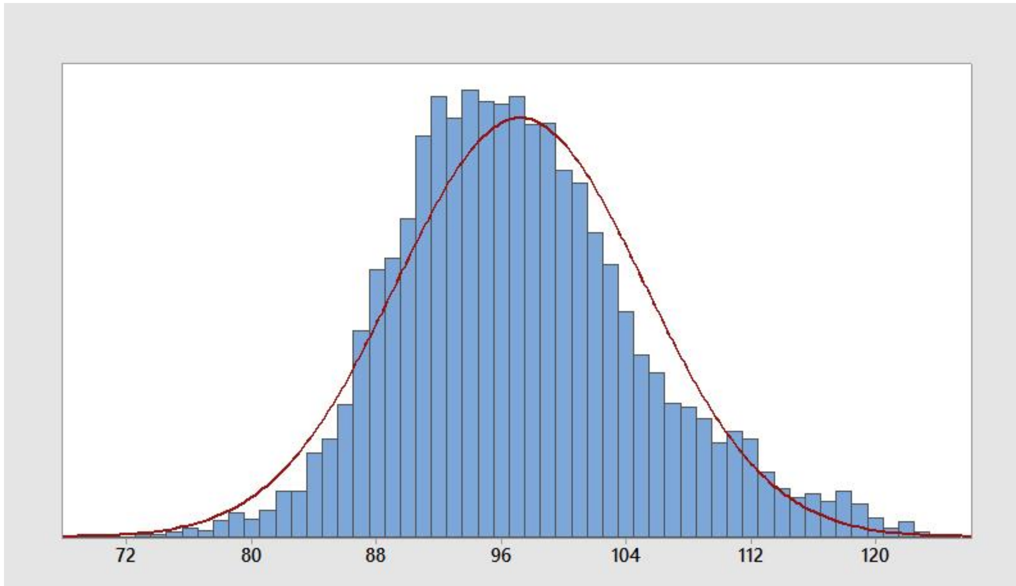


**Figure D7: Distribution plot for subject 2 of the second site measurements.**

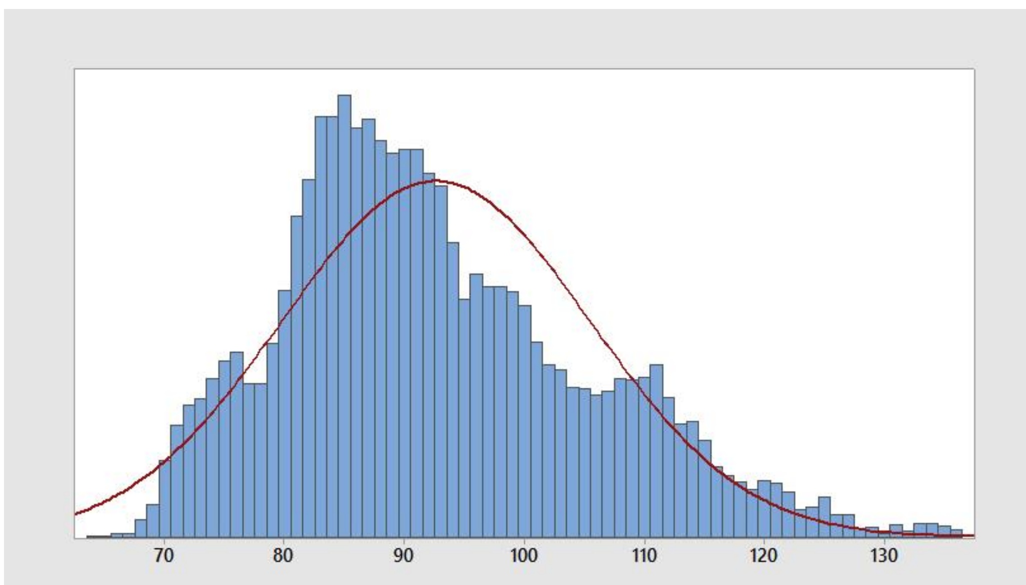


**Figure D8: Distribution plot for subject 3 of the second site measurements.**

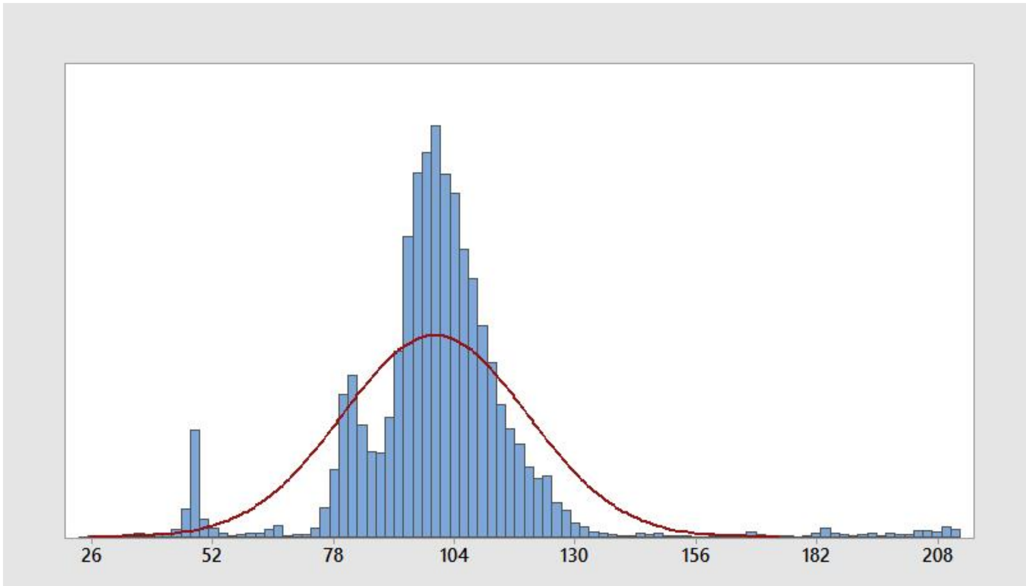


**Figure D9: Distribution plot for subject 4 of the second site measurements.**

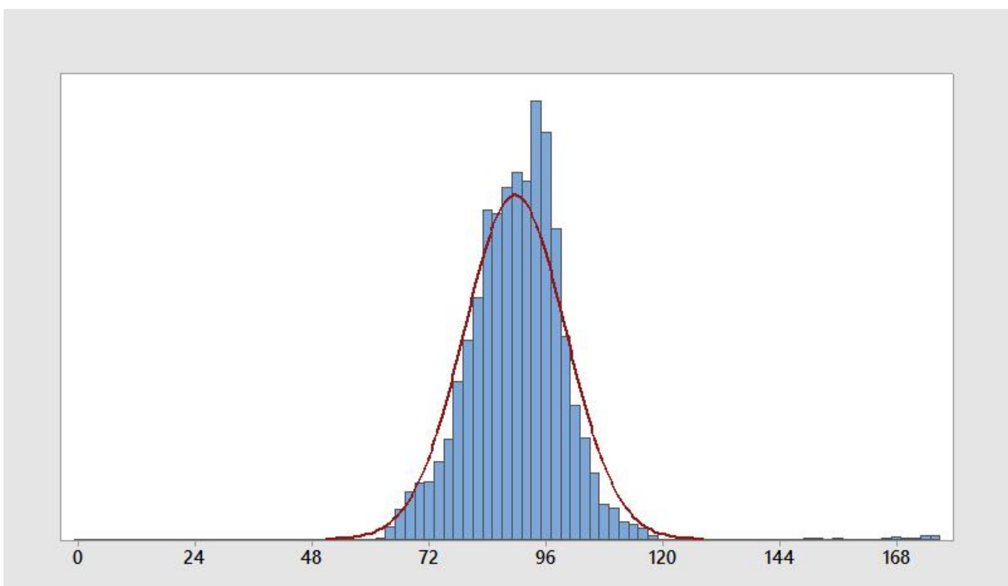


**Figure D10: Distribution plot for subject 5 of the second site measurements.**

## 3. Third Construction Site Measurements

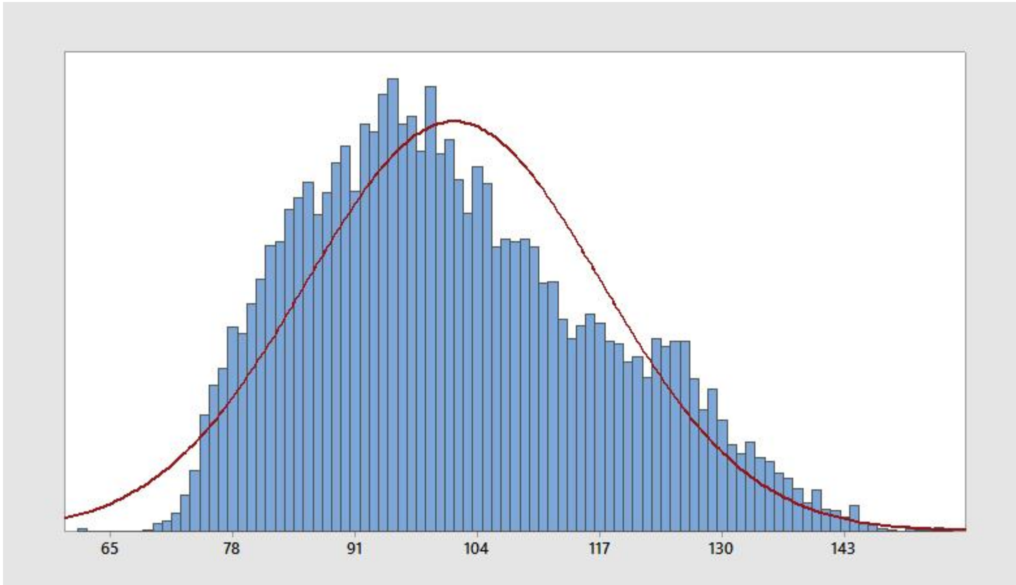


**Figure D11: Distribution plot for subject 1 of the third site measurements.**

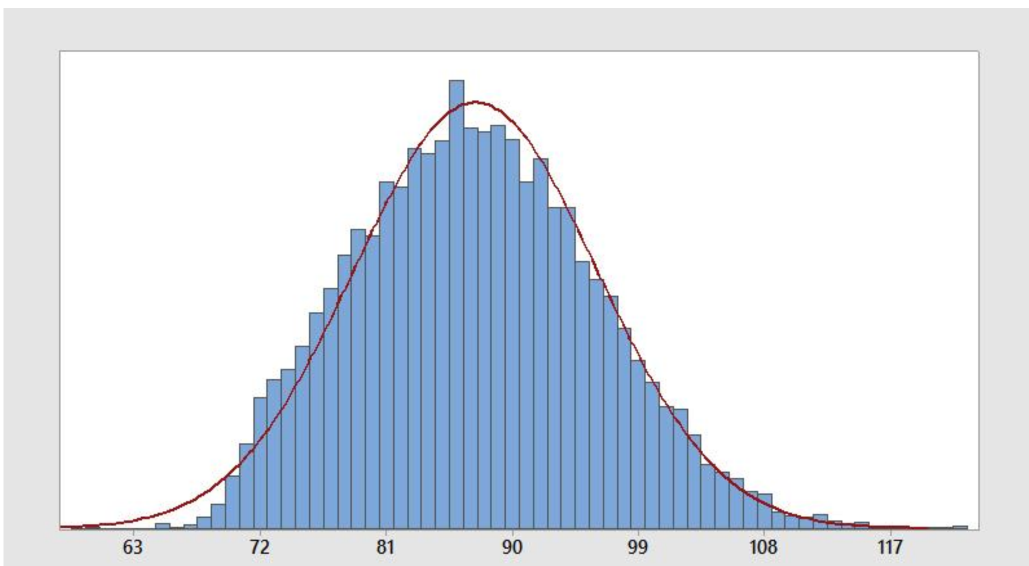


**Figure D12: Distribution plot for subject 2 of the third site measurements.**

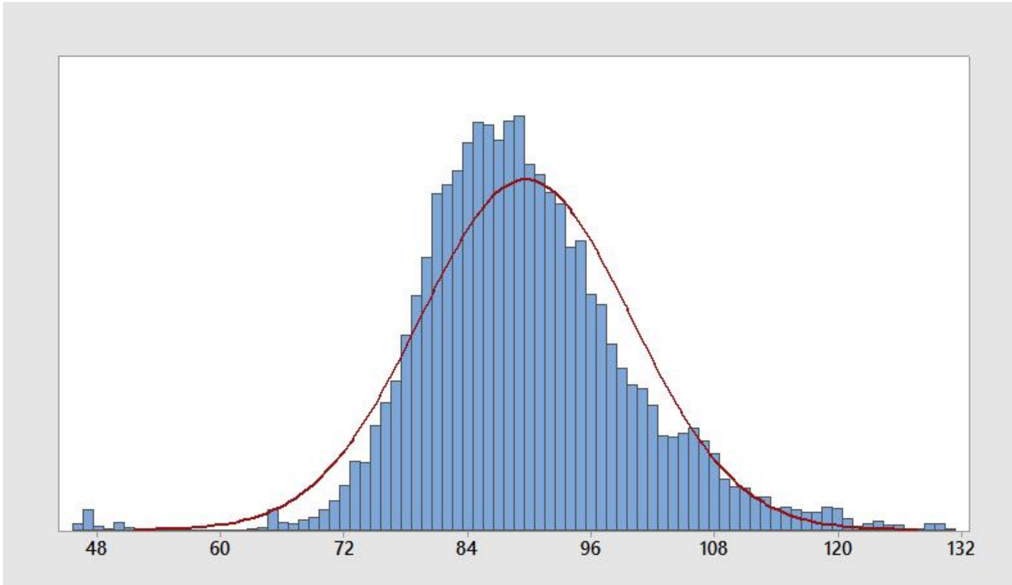


**Figure D13: Distribution plot for subject 3 of the third site measurements.**

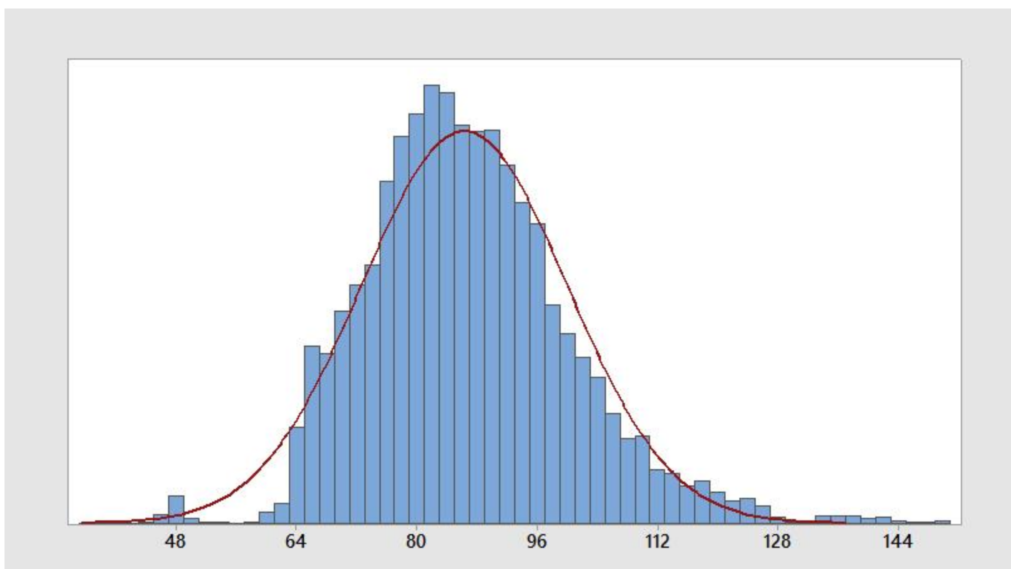


**Figure D14: Distribution plot for subject 4 of the third site measurements.**

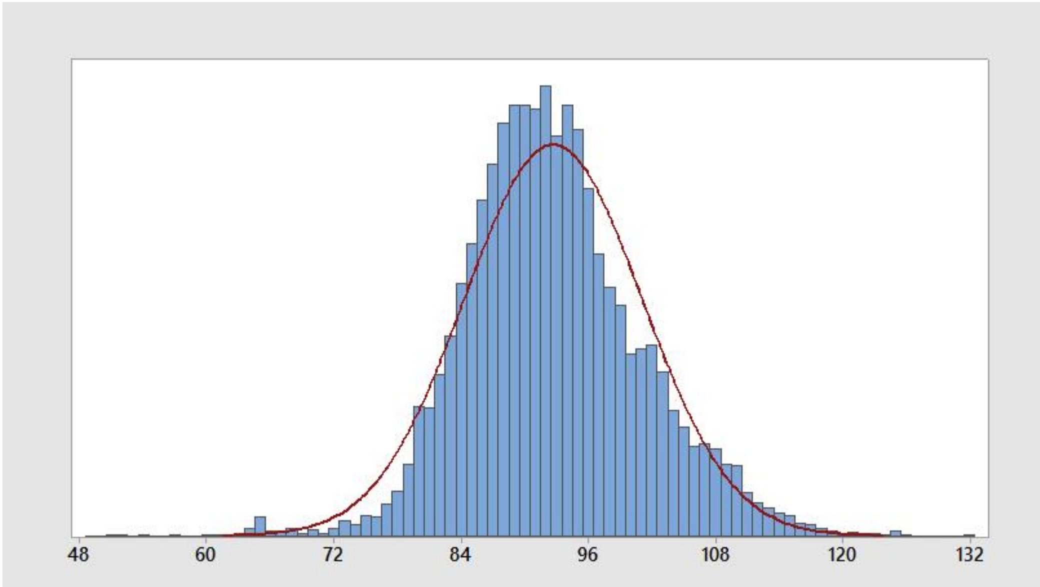


**Figure D15: Distribution plot for subject 5 of the third site measurements.**

## 4. Fourth Construction Site Measurements

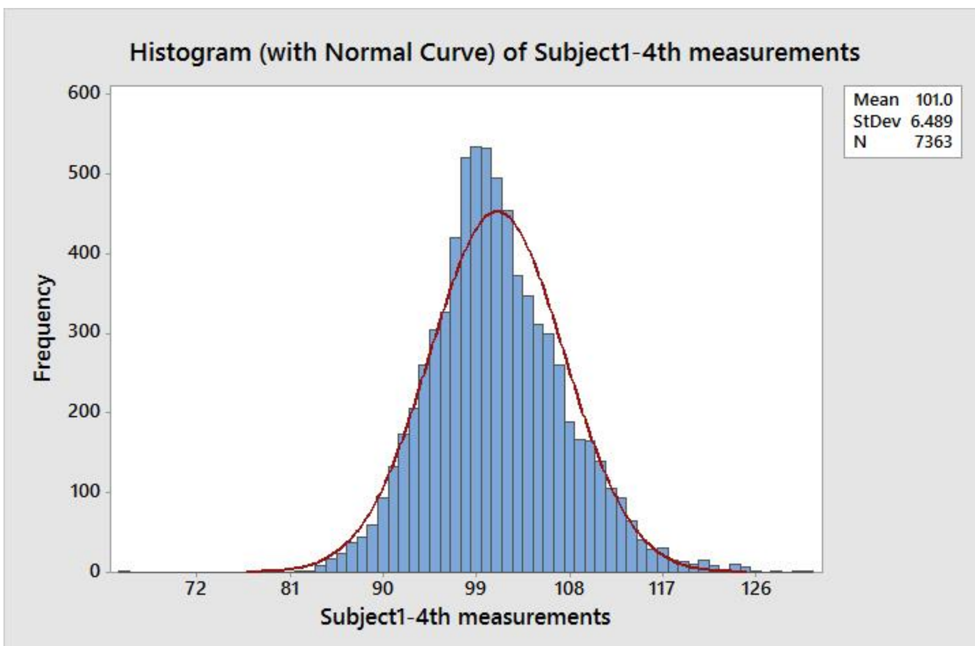


**Figure D16: Distribution plot for subject 1 of the fourth site measurements.**

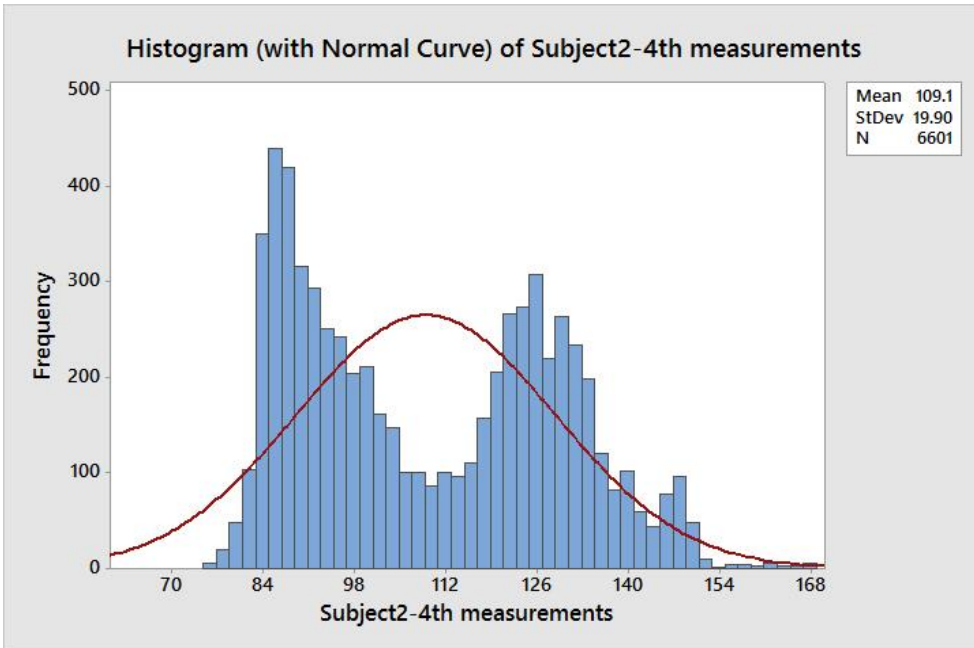


**Figure D17: Distribution plot for subject 2 of the fourth site measurements.**

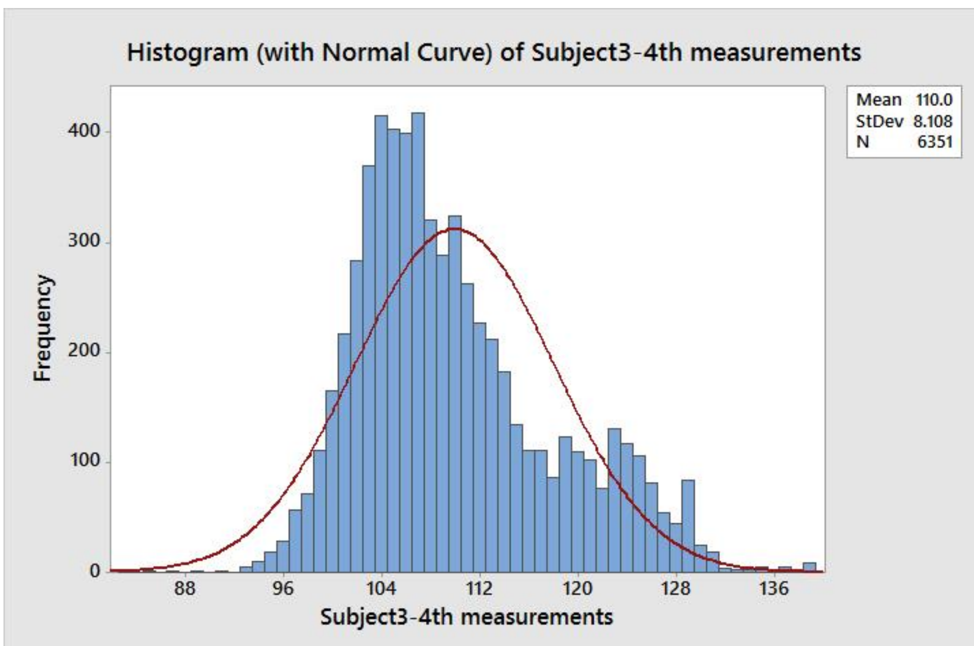


**Figure D18: Distribution plot for subject 3 of the fourth site measurements.**

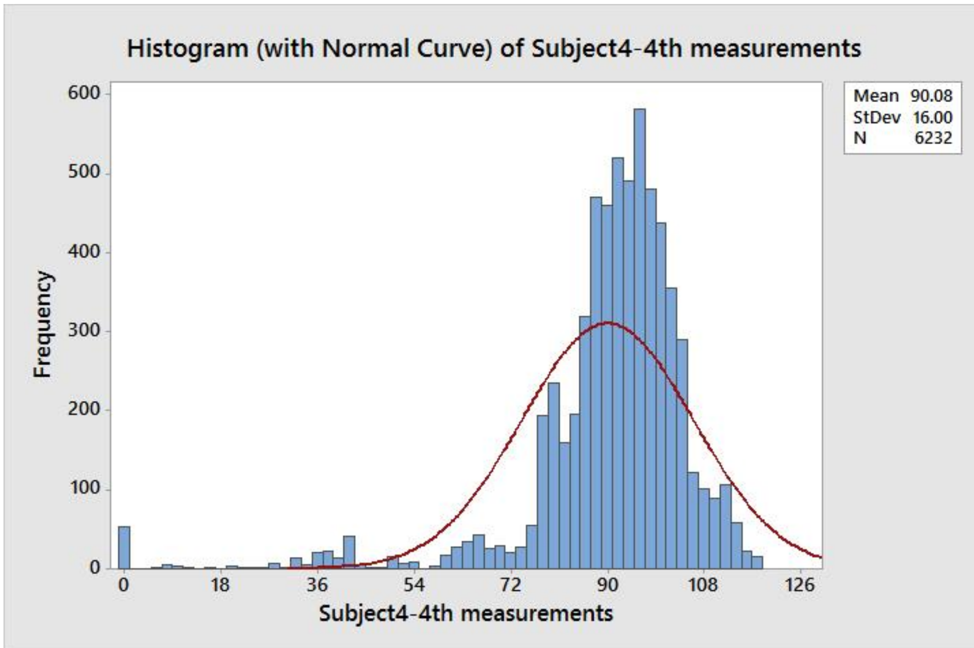


**Figure D19: Distribution plot for subject 4 of the fourth site measurements.**

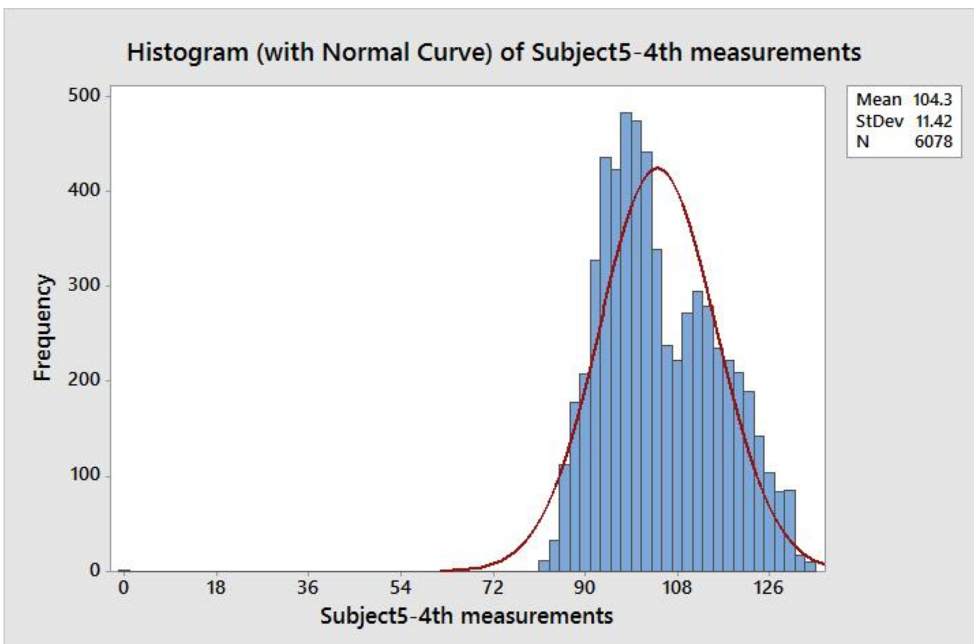


**Figure D20: Distribution plot for subject 5 of the fourth site measurements.**

## 5. Fifth Construction Site Measurements

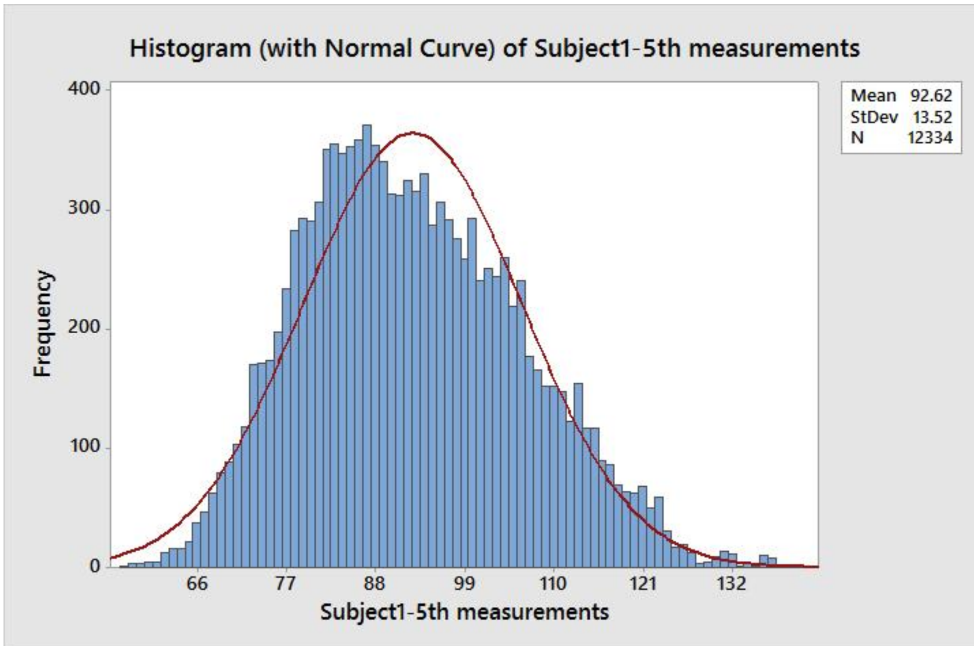


**Figure D21: Distribution plot for subject 1 of the fifth site measurements.**

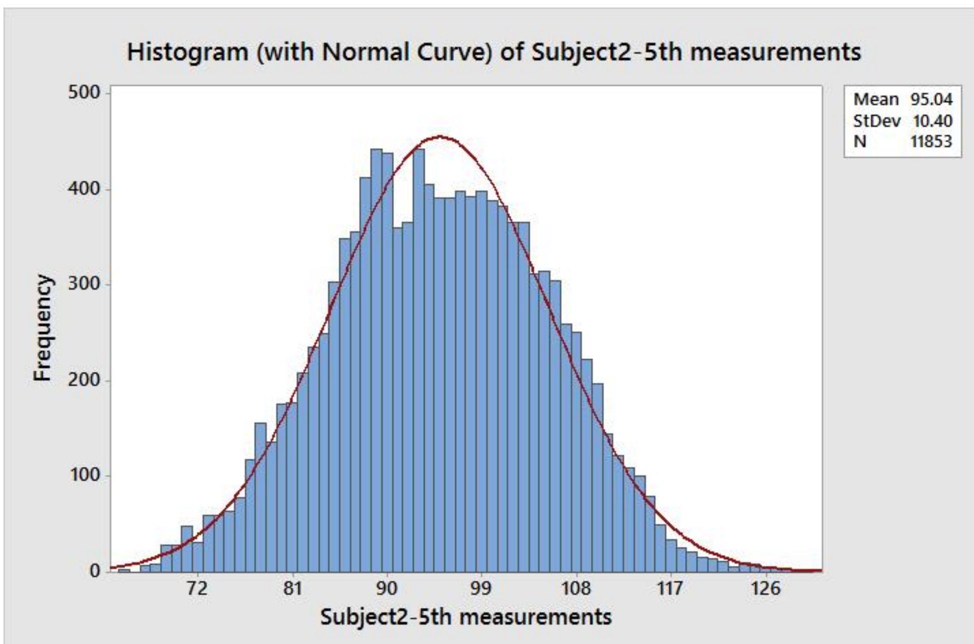


**Figure D22: Distribution plot for subject 2 of the fifth site measurements.**

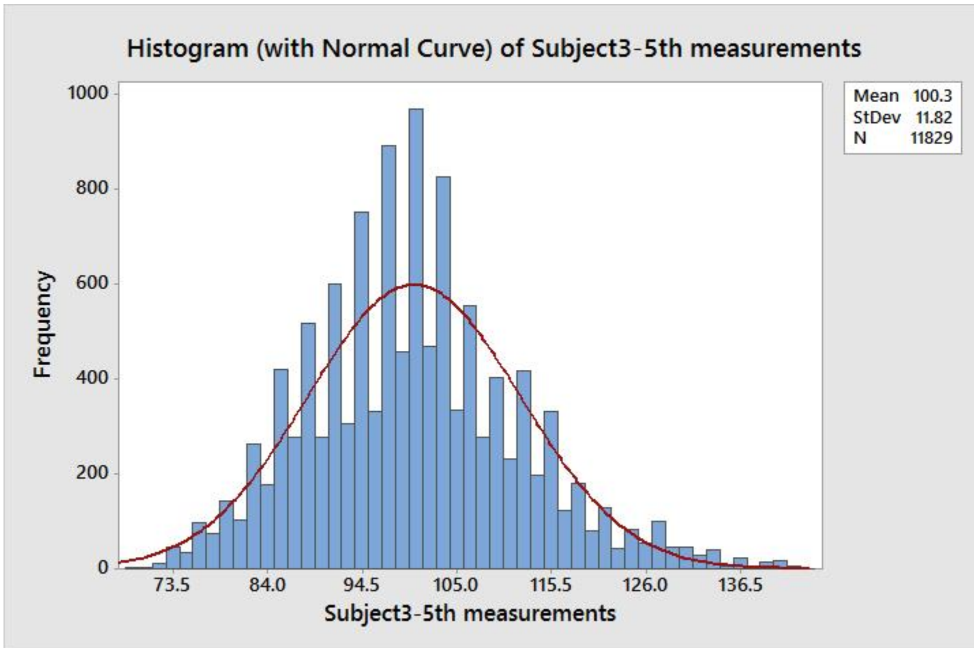


**Figure D23: Distribution plot for subject 3 of the fifth site measurements.**

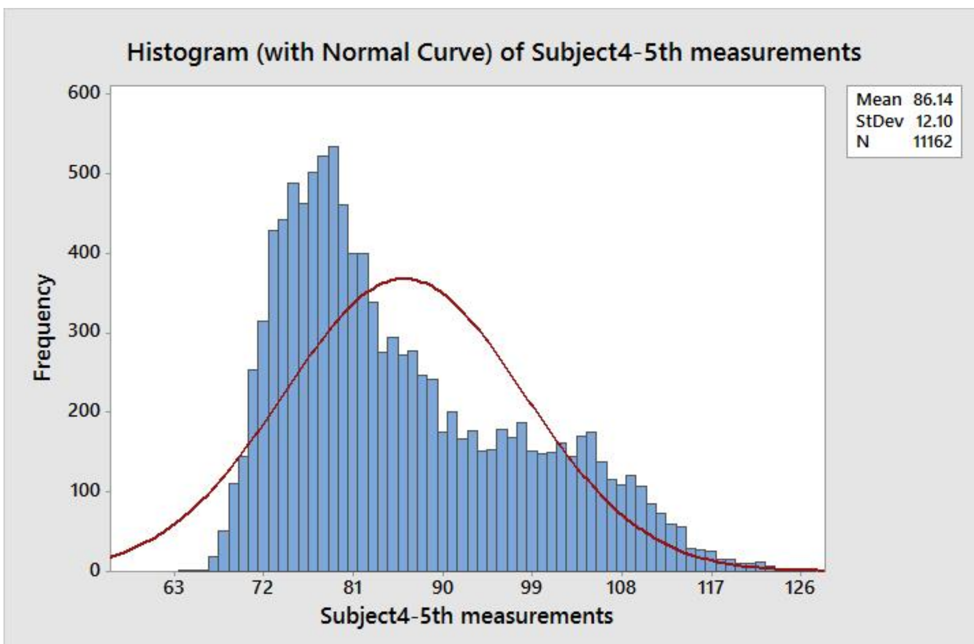


**Figure D24: Distribution plot for subject 4 of the fifth site measurements.**

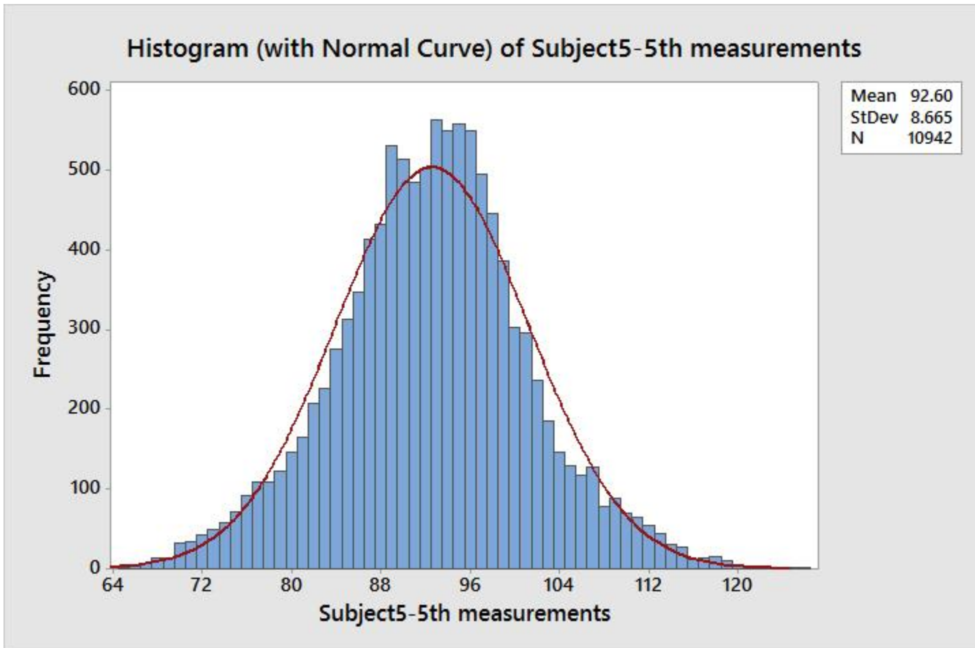


**Figure D25: Distribution plot for subject 5 of the fifth site measurements.**

## 6. Sixth Construction Site Measurements

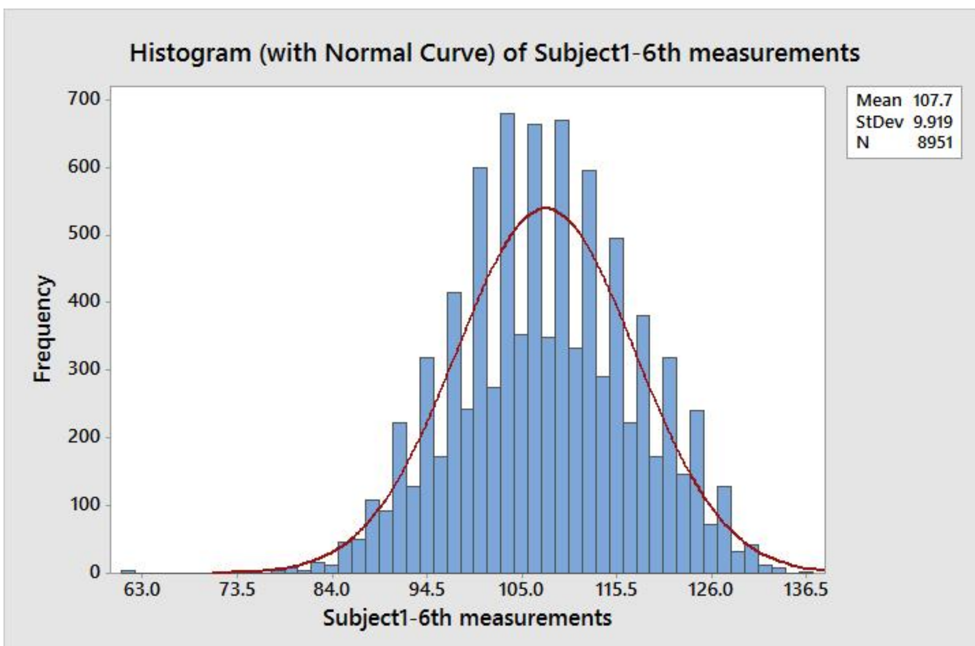


**Figure D26: Distribution plot for subject 1 of the sixth site measurements.**

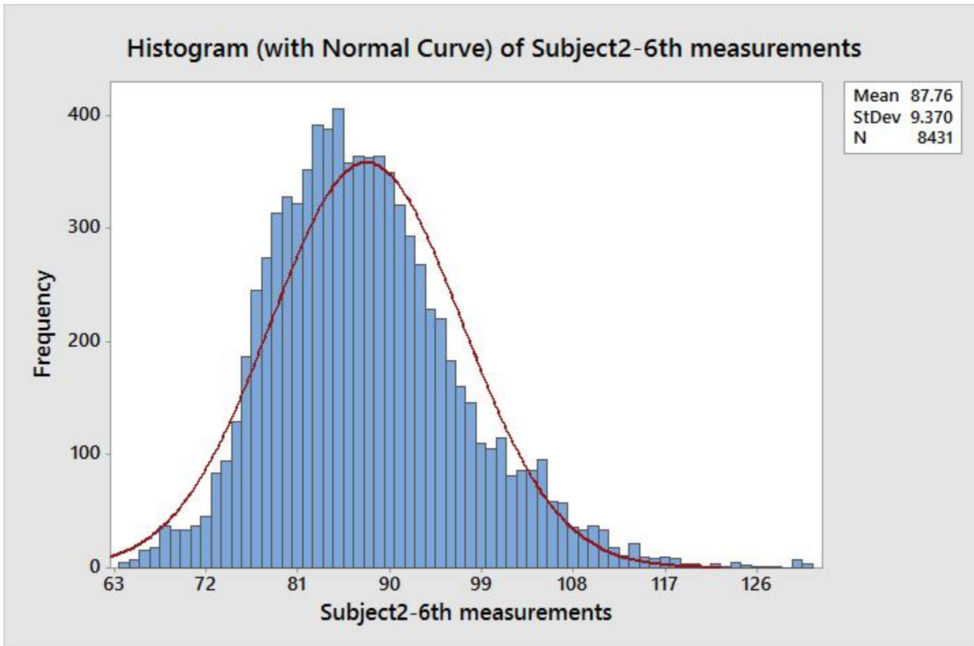


**Figure D27: Distribution plot for subject 2 of the sixth site measurements.**

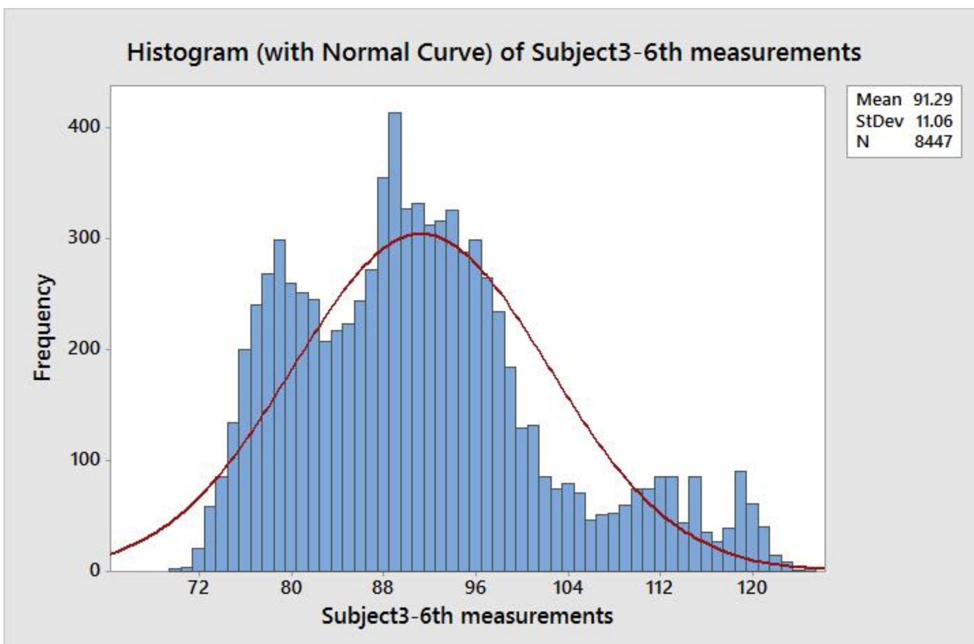


**Figure D28: Distribution plot for subject 2 of the sixth site measurements.**

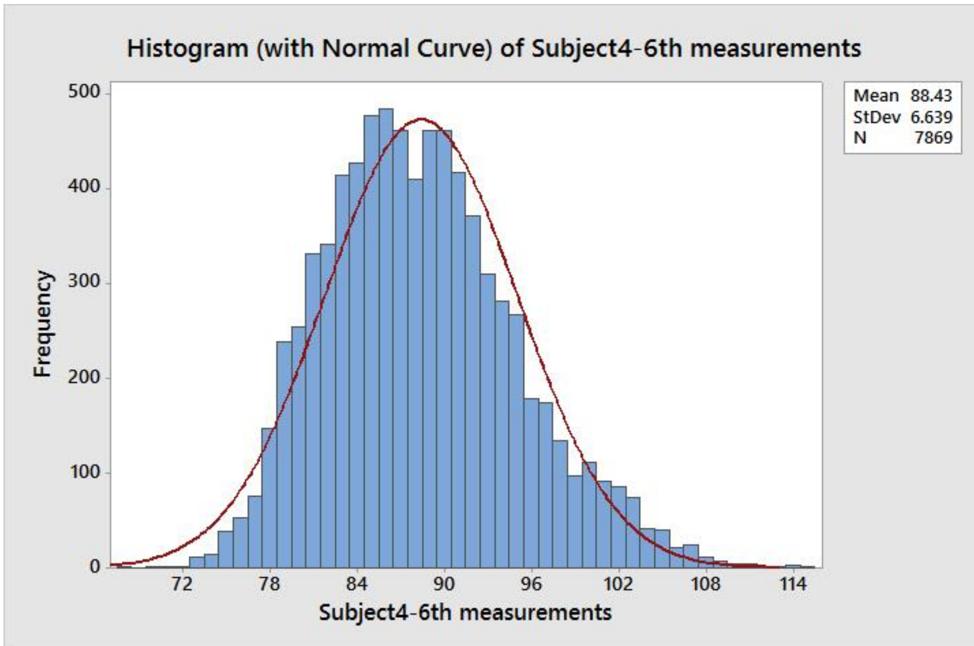


**Figure D29: Distribution plot for subject 4 of the sixth site measurements.**

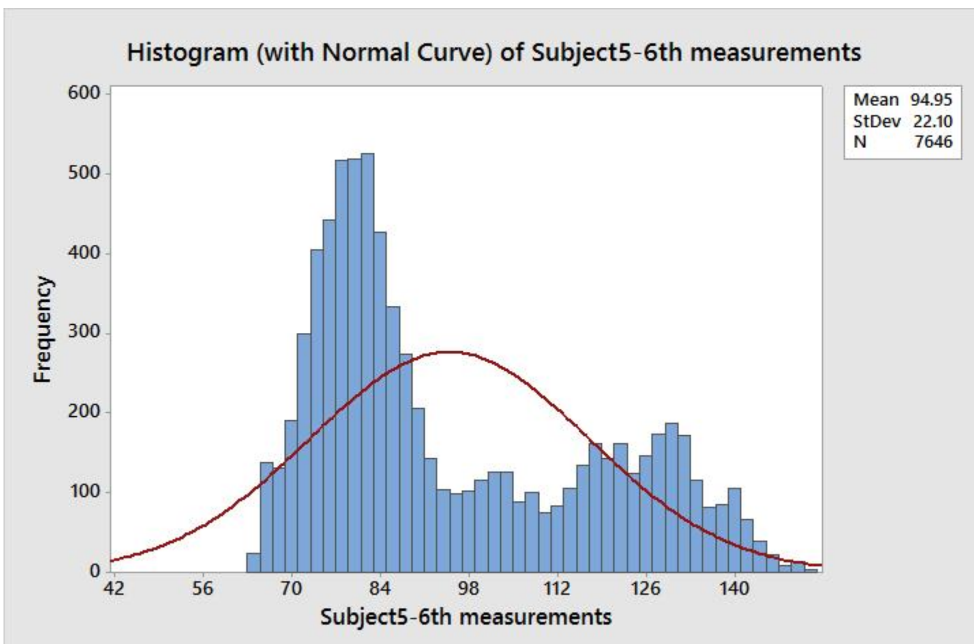


**Figure D30: Distribution plot for subject 5 of the sixth site measurements.**

## 7. Seventh Construction Site Measurements

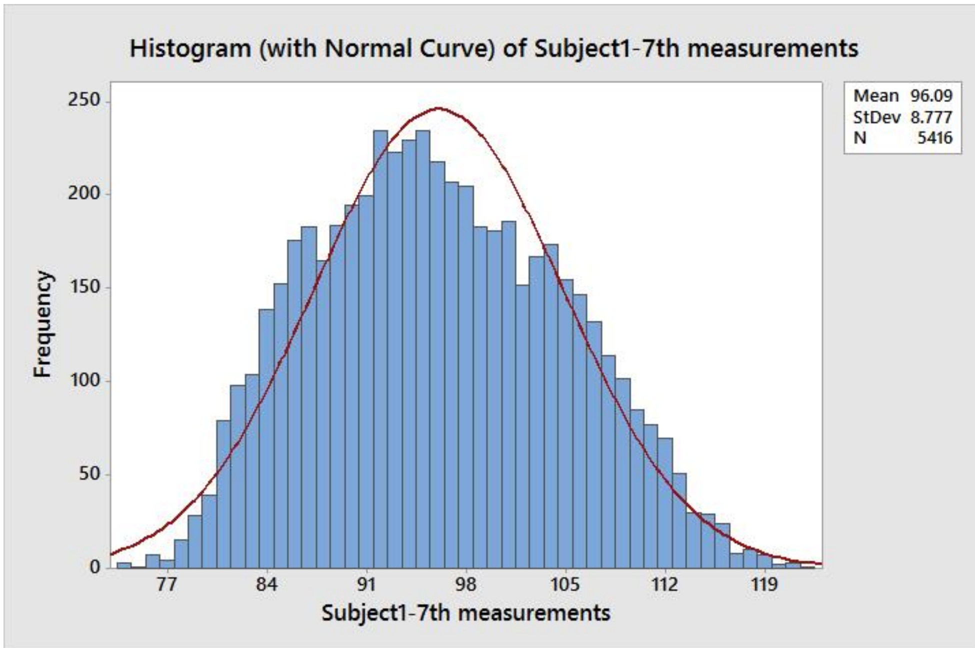


**Figure D31: Distribution plot for subject 1 of the seventh site measurements.**

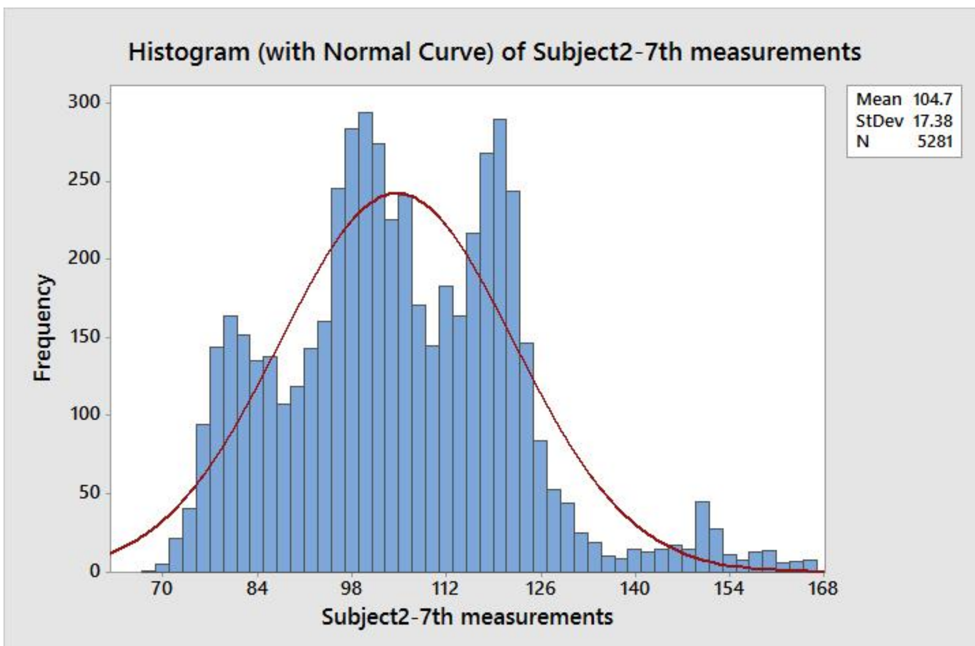


**Figure D32: Distribution plot for subject 1 of the seventh site measurements.**

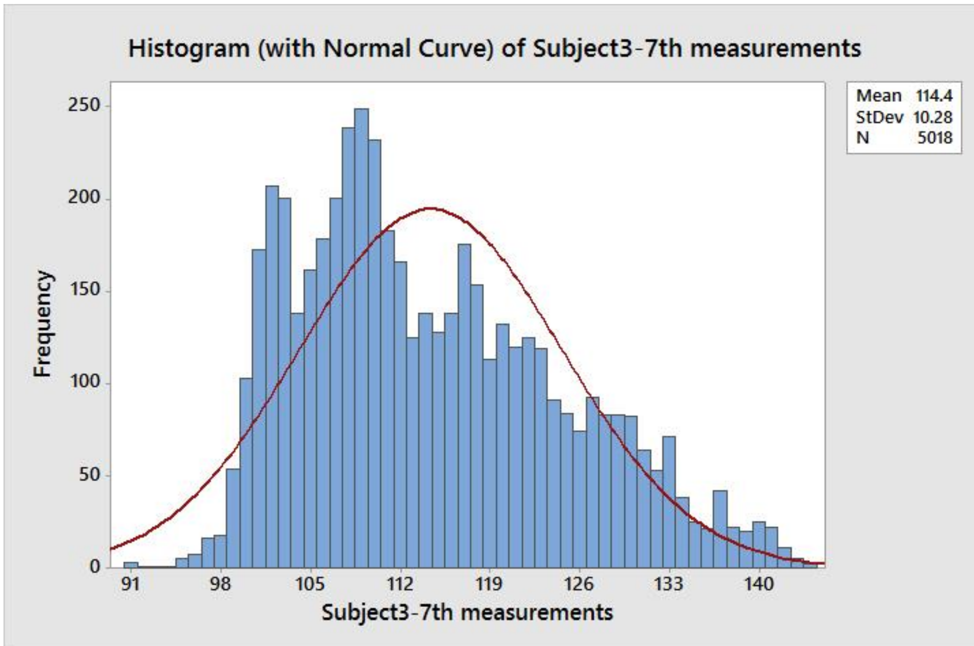


**Figure D33: Distribution plot for subject 3 of the seventh site measurements.**

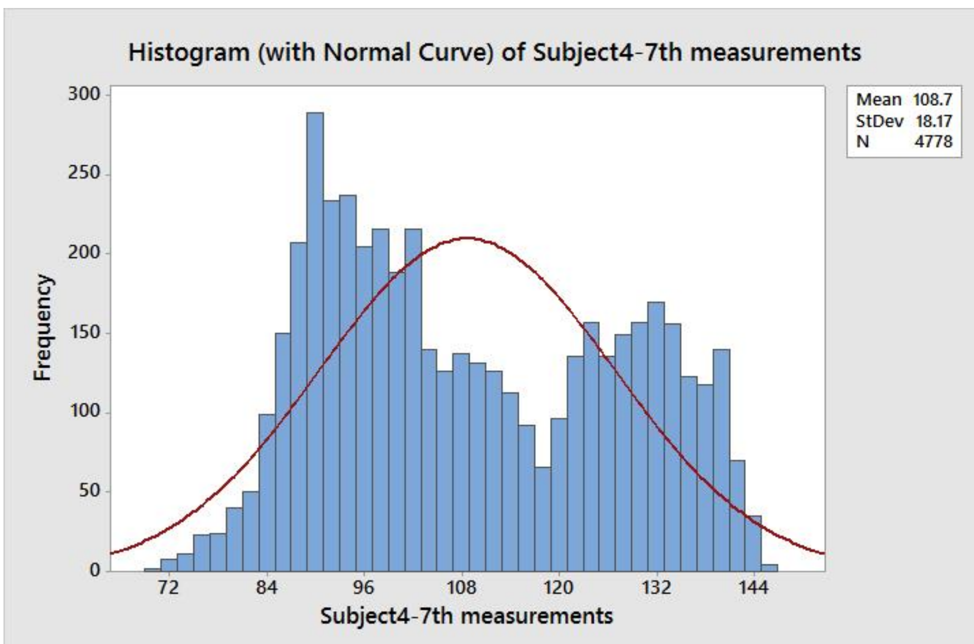


**Figure D34: Distribution plot for subject 4 of the seventh site measurements.**

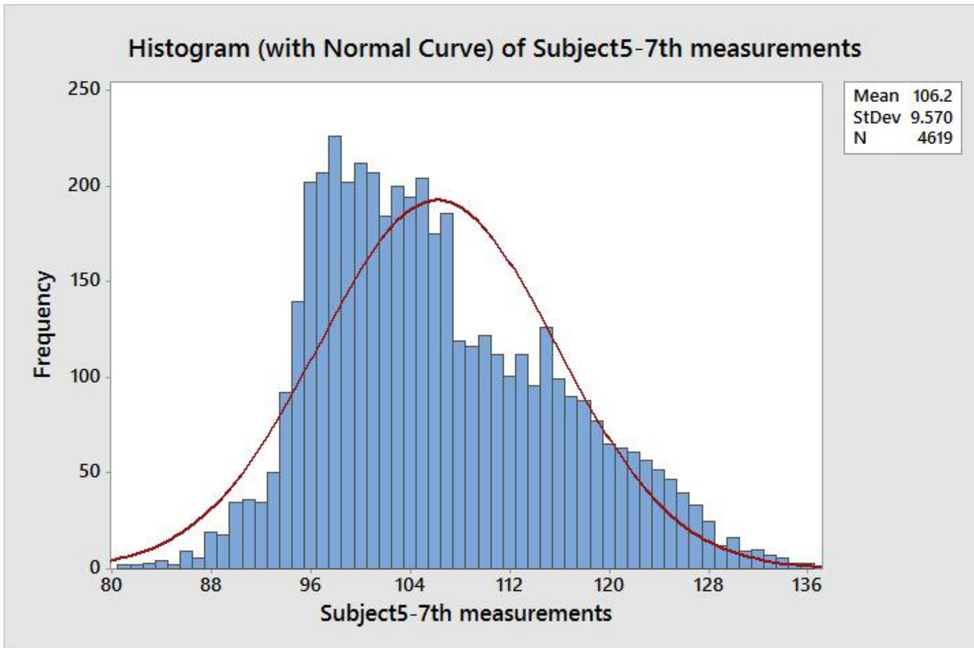


**Figure D35: Distribution plot for subject 5 of the seventh site measurements.**

## Appendix-E: Grubbs' Test Results.

In this appendix, Minitab software output for Two-tailed Grubbs' test ("smallest and largest value is an outlier") for both HR and BR of each participant in construction site measurements.

### 1. First Site Measurements:

#### 1.1 Subject 1: (Session1) Outlier Test (BR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable      N    Mean  StDev    Min     Max     G      P
HR(bPM)_1  4742  103.64  11.63  75.00  132.00  2.46  1.000
* NOTE * No outlier at the 5% level of significance
```

#### 1.2 Subject 1: (Session2) Outlier Test (BR (bpm))

```
 Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                     N    Mean   StDev     Min      Max     G      P
Subject 1 (HR)  Session   3637  86.849  13.426  68.000  134.000  3.51  1.000
* NOTE * No outlier at the 5% level of significance
```

#### 1.3 Subject 1: (Session3) Outlier Test (BR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                     N    Mean   StDev     Min      Max     G      P
Subject 1 (HR)  Session   8909  98.549  11.263  52.000  134.000  4.13  0.317
* NOTE * No outlier at the 5% level of significance
```

#### 1.4 Subject 2: (Session1) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                     N    Mean  StDev    Min     Max     G      P
Subject 2 (HR) Session 1  4743  108.64  13.10  71.00  154.00  3.46  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.5 Subject 2: (Session2) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean  StDev     Min      Max     G      P
Sunbject 2 (HR) Session   3637  85.522  9.758  62.000  137.000  5.28  0.000
Outlier
Variable                   Outlier
Sunbject 2 (HR) Session      137, 136, 135, 133, 132, 130 128, 127
After removing the outliers
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean  StDev     Min      Max     G      P
Sunbject 2 (HR) Session   3627  85.396  9.468  62.000  126.000  4.29  0.064
* NOTE * No outlier at the 5% level of significance
```

## 1.6 Subject 2: (Session3) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean   StDev     Min      Max     G      P
Subject 2 (HR) Session 3  8412  96.164  12.220  57.000  140.000  3.59  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.7 Subject 3: (Session1) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable              N    Mean   StDev     Min      Max     G      P
Sub3 (HR) Session1  4743  94.430  10.128  66.000  132.000  3.71  0.976
* NOTE * No outlier at the 5% level of significance
```

## 1.8 Subject 3: (Session2) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable              N    Mean   StDev     Min      Max     G      P
Sub3 (HR) Session2  3637  85.087  11.254  59.000  123.000  3.37  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.9 Subject 3: (Session3) Outlier Test (HR (bpm))

```
Method
```

```
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean  StDev     Min      Max     G      P
Sub3 (HR) Session3  2195  68.057  9.347  53.000  113.000  4.81  0.003
Outlier
Variable               Outlier
Sub3 (HR) Session3       113, 112, 111, 110, 109, 107
After removing the outliers
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean  StDev     Min      Max     G      P
Sub3 (HR) Session3  2186  67.881  8.953  53.000  105.000  4.15  0.072
* NOTE * No outlier at the 5% level of significance
```

## 1.10 Subject 4: (Session1) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean  StDev    Min     Max     G      P
Subject4 (HR) Session1  4743  116.33  11.87  79.00  151.00  3.15  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.11 Subject 4: (Session2) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean  StDev    Min     Max     G      P
Subject4 (HR) Session2  3697  105.31  12.56  81.00  141.00  2.84  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.12 Subject 4: (Session3) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean  StDev    Min     Max     G      P
Subject4 (HR) Session3  8023  100.48   8.85  49.00  135.00  5.82  0.000
Outlier
Variable                   Outlier
Subject4 (HR) Session3       49, 57
After removing the outliers
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean  StDev    Min     Max     G      P
Subject4 (HR) Session3  8020  100.50   8.81  64.00  135.00  4.14  0.270
* NOTE * No outlier at the 5% level of significance
```

## 1.13 Subject 5: (Session1) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean   StDev     Min      Max     G      P
Subject5 (HR) Session1  4743  87.557  11.295  59.000  119.000  2.78  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.14 Subject 5: (Session2) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean   StDev     Min      Max     G      P
Subject5 (HR) Session2  4116  75.921  17.627  51.000  123.000  2.67  1.000
* NOTE * No outlier at the 5% level of significance
```

## 1.15 Subject 5: (Session3) Outlier Test (HR (bpm))

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                   N    Mean   StDev     Min      Max     G      P
Subject5 (HR) Session3  7450  79.837  12.407  50.000  118.000  3.08  1.000
* NOTE * No outlier at the 5% level of significance
```

# 2. Second Site Measurements:

## 2.1 Outlier Test: Sub1 (HR) Session 1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean   StDev     Min      Max     G      P
Sub1 (HR) Session 1  7245  90.307  13.685  57.000  129.000  2.83  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.2 Outlier Test: Sub1 (HR) Session 2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean   StDev     Min      Max     G      P
Sub1 (HR) Session 2  4500  78.773  13.587  52.000  117.000  2.81  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.3 Outlier Test: Sub1 (HR) Session 3

```
Method
```

```
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub1 (HR) Session 3  4620  89.974  9.952  60.000  117.000  3.01  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.4 Outlier Test: Sub2 (HR) Session 1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub2 (HR) Session 1  7026  99.673  9.199  69.000  125.000  3.33  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.5 Outlier Test: Sub2 (HR) Session 2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub2 (HR) Session 2  4500  93.710  6.617  73.000  121.000  4.12  0.165
* NOTE * No outlier at the 5% level of significance
```

## 2.6 Outlier Test: Sub2 (HR) Session 3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub2 (HR) Session 3  4630  96.892  5.317  79.000  114.000  3.37  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.7 Outlier Test: Sub3 (HR) Session 1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean   StDev     Min      Max     G      P
Sub3 (HR) Session 1  6891  99.354  13.792  64.000  136.000  2.66  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.8 Outlier Test: Sub3 (HR) Session 2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean   StDev     Min      Max     G      P
Sub3 (HR) Session 2  4500  87.723  11.616  66.000  118.000  2.61  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.9 Outlier Test: Sub3 (HR) Session 3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub3 (HR) Session 3  4641  87.343  6.367  68.000  111.000  3.72  0.931
* NOTE * No outlier at the 5% level of significance
```

## 2.10 Outlier Test: Sub4 (HR) Session 1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev    Min     Max     G      P
Sub4 (HR) Session 1  8198  103.47  26.52  24.00  212.00  4.09  0.348
* NOTE * No outlier at the 5% level of significance
```

## 2.11 Outlier Test: Sub4 (HR) Session 2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean   StDev     Min      Max     G      P
Sub4 (HR) Session 2  4500  95.041  12.118  72.000  132.000  3.05  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.12 Outlier Test: Sub4 (HR) Session 3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub4 (HR) Session 3  4652  97.863  7.431  71.000  118.000  3.62  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.13 Outlier Test: Sub5 (HR) Session 1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean   StDev     Min      Max     G      P
Sub5 (HR) Session 1  6647  96.016  10.092  67.000  176.000  7.93  0.000
Outlier
Variable               Outlier
Sub5 (HR) Session 1      176, 175, 174, 173, 172, 171, 170, 169, 167, 166,
                         165, 164, 163, 160, 157, 156, 155, 152, 151, 150,
                         148, 146, 143, 141, 140, 139, 138, 136, 133, 131
```

## 2.14 Outlier Test: Sub5 (HR) Session 2

```
Method
Null hypothesis         All data values come from the same normal population
```

```
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub5 (HR) Session 2  4500  83.134  8.989  62.000  105.000  2.43  1.000
* NOTE * No outlier at the 5% level of significance
```

## 2.15 Outlier Test: Sub5 (HR) Session 3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev     Min      Max     G      P
Sub5 (HR) Session 3  4632  86.860  6.248  66.000  107.000  3.34  1.000
* NOTE * No outlier at the 5% level of significance
```

# 3. Third Site Measurements:

## 3.1 Outlier Test: Sub1 (HR) Session1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable                N    Mean  StDev    Min     Max     G      P
Sub1 (HR) Session1  11826  104.56  15.95  62.00  154.00  3.10  1.000
* NOTE * No outlier at the 5% level of significance
```

## 3.2 Outlier Test: Sub1 (HR) Session2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub1 (HR) Session2  2520  94.248  12.179  69.000  131.000  3.02  1.000
* NOTE * No outlier at the 5% level of significance
```

## 3.3 Outlier Test: Sub1 (HR) Session3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub1 (HR) Session3  2202  93.374  11.953  70.000  130.000  3.06  1.000
* NOTE * No outlier at the 5% level of significance
```

## 3.4 Outlier Test: Sub2 (HR) Session1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
```

Sub2 (HR) Session1  8258  92.776  21.956  20.000  240.000  6.71  0.000
Outlier
Variable             Outlier
Sub2 (HR) Session1     240, 239, 237, 236, 234, 231, 222, 221, 220, 219, 218, 217, 216, 215, 214, 213, 212, 211, 209, 208, 207, 206, 204, 203, 202, 201, 200, 198, 197, 196, 195, 193, 190, 189, 188, 186, 184, 182, 180, 177, 176, 175, 174, 172, 171, 170, 169, 168, 166, 165, 163, 162, 161, 20, 21, 22, 158, 25, 151, 31, 147, 146, 145, 144, 36, 142, 38, 140, 138, 42, 137, 136, 135, 134, 133, 132, 131, 50, 129, 51, 52, 54, 127, 126, 124, 123,

After Removing the outliers

Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      $\alpha = 0.05$

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub2 (HR) Session1 | 7995 | 89.504 | 7.338 | 59.000 | 122.000 | 4.43 | 0.075 |

* NOTE * No outlier at the 5% level of significance

## 3.5 Outlier Test: Sub2 (HR) Session2

Method

Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      $\alpha = 0.05$

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub2 (HR) Session2 | 2520 | 81.479 | 8.110 | 67.000 | 114.000 | 4.01 | 0.149 |

* NOTE * No outlier at the 5% level of significance

## 3.6 Outlier Test: Sub2 (HR) Session3

Method

Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      $\alpha = 0.05$

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub2 (HR) Session3 | 5332 | 86.952 | 9.457 | 67.000 | 116.000 | 3.07 | 1.000 |

* NOTE * No outlier at the 5% level of significance

## 3.7 Outlier Test: Sub3 (HR) Session1

Method

Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      $\alpha = 0.05$

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub3 (HR) Session1 | 7776 | 87.256 | 9.594 | 38.000 | 121.000 | 5.13 | 0.002 |

Outlier
Variable               Outlier
Sub3 (HR) Session1        38, 39, 40, 42, 44, 45, 46

After removing the outliers

Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      $\alpha = 0.05$

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub3 (HR) Session1 | 7756 | 87.377 | 9.307 | 46.000 | 121.000 | 4.45 | 0.067 |

* NOTE * No outlier at the 5% level of significance

### 3.8 Outlier Test: Sub3 (HR) Session2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean  StDev     Min      Max     G      P
Sub3 (HR) Session2  2520  91.340  9.849  71.000  120.000  2.91  1.000
* NOTE * No outlier at the 5% level of significance
```

### 3.9 Outlier Test: Sub3 (HR) Session3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub3 (HR) Session3  5200  92.207  11.010  65.000  131.000  3.52  1.000
* NOTE * No outlier at the 5% level of significance
```

### 3.10 Outlier Test: Sub4 (HR) Session1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub4 (HR) Session1  7540  90.889  13.777  35.000  187.000  6.98  0.000
Outlier
Variable              Outlier
Sub4 (HR) Session1      187, 186, 183, 182, 181, 180, 179, 178, 177, 176,
                        175, 174, 172, 169, 166, 164, 163, 162, 160, 158,
                        157, 155, 154, 152, 151, 150, 149, 146, 35
After removing the outliers
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub4 (HR) Session1  7490  90.457  12.189  36.000  143.000  4.47  0.058
* NOTE * No outlier at the 5% level of significance
```

### 3.11 Outlier Test: Sub4 (HR) Session2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean  StDev     Min      Max     G      P
Sub4 (HR) Session2  2520  83.137  9.537  64.000  114.000  3.24  1.000
* NOTE * No outlier at the 5% level of significance
```

### 3.12 Outlier Test: Sub4 (HR) Session3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
```

```
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub4 (HR) Session3  5628  83.176  17.769  58.000  166.000  4.66  0.017
Outlier
Variable               Outlier
Sub4 (HR) Session3       166, 165, 164, 163, 162, 161, 160, 158, 157,
                         156, 155, 154, 153, 151
After removing the outliers
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub4 (HR) Session3  5556  82.160  15.454  58.000  150.000  4.39  0.062
* NOTE * No outlier at the 5% level of significance
```

## 3.13 Outlier Test: Sub5 (HR) Session1

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean   StDev     Min      Max     G      P
Sub5 (HR) Session1  7441  95.636  29.686  23.000  240.000  4.86  0.008
Outlier
Variable             Outlier
Sub5 (HR) Session1    240, 239, 238, 237, 235, 234, 233, 232, 231, 230, 229,
                      228, 227, 225, 219, 217, 216, 215, 214, 213, 211, 210,
                      209, 206, 205, 201, 198, 196, 194, 192, 190, 189, 186,
                      185, 182, 180, 178, 177, 175, 173, 172, 171, 170, 169,
                      168, 167, 166, 165, 164, 163, 162, 161, 158, 23, 24,
                      25, 156, 25, 155, 154, 28, 27, 29, 152, 151, 150, 31,
                      32, 33, 148, 146, 35, 36, 144, 37, 143, 38, 39, 141,
                      40, 139, 42, 43, 137, 44, 45, 46, 134, 47, 48
After removing the outliers
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean  StDev     Min      Max     G      P
Sub5 (HR) Session1  7026  90.371  9.428  49.000  132.000  4.42  0.070
* NOTE * No outlier at the 5% level of significance
```

## 3.14 Outlier Test: Sub5 (HR) Session2

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
Variable               N    Mean  StDev     Min      Max     G      P
Sub5 (HR) Session2  2520  93.875  6.274  77.000  113.000  3.05  1.000
* NOTE * No outlier at the 5% level of significance
```

## 3.15 Outlier Test: Sub5 (HR) Session3

```
Method
Null hypothesis         All data values come from the same normal population
Alternative hypothesis  Smallest or largest data value is an outlier
Significance level      α = 0.05
Grubbs' Test
```

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub5 (HR) Session3 | 802 | 93.295 | 12.817 | 46.460 | 194.432 | 7.89 | 0.000 |

Outlier

| Variable | Outlier |
|---|---|
| Sub5 (HR) Session3 | 57,60, 61, 62, 63, 65 |

## 4. Fourth Site Measurements:

Method

| | |
|---|---|
| Null hypothesis | All data values come from the same normal population |
| Alternative hypothesis | Smallest or largest data value is an outlier |
| Significance level | α = 0.05 |

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Sub 1 HR (session 1) | 3564 | 101.88 | 6.08 | 82.00 | 122.00 | 3.31 | 1.000 |
| Sub 1 HR (session 2) | 894 | 96.290 | 3.364 | 87.000 | 107.000 | 3.18 | 1.000 |
| Sub 1 HR (session 3) | 2904 | 101.45 | 7.04 | 82.00 | 131.00 | 4.20 | 0.076 |
| Sub 2 HR (session 1) | 2027 | 126.76 | 14.39 | 92.00 | 168.00 | 2.87 | 1.000 |
| Sub 2 HR (session 2) | 755 | 87.555 | 4.260 | 78.000 | 102.000 | 3.39 | 0.504 |
| Sub 2 HR (session 3) | 3819 | 104.00 | 16.95 | 75.00 | 149.00 | 2.65 | 1.000 |
| Sub 3 HR (session 1) | 4364 | 109.15 | 6.36 | 83.00 | 138.00 | 4.53 | 0.025 |
| Sub 3 HR (session 2) | 901 | 101.79 | 3.55 | 93.00 | 116.00 | 4.01 | 0.052 |
| Sub 3 HR (session 3) | 1074 | 119.94 | 6.95 | 98.00 | 133.00 | 3.16 | 1.000 |
| Sub 4 HR (session 1) | 4387 | 93.703 | 9.514 | 52.000 | 117.000 | 4.38 | 0.050 |
| Sub 4 HR (session 2) | 574 | 79.930 | 3.168 | 73.000 | 92.000 | 3.81 | 0.073 |
| Sub 4 HR (session 3) | 1064 | 93.219 | 11.394 | 49.000 | 118.000 | 3.88 | 0.105 |
| Sub 5 HR (session 1) | 3712 | 110.44 | 9.42 | 92.00 | 134.00 | 2.50 | 1.000 |
| Sub 5 HR (session 2) | 518 | 96.878 | 2.935 | 91.000 | 107.000 | 3.45 | 0.273 |
| Sub 5 HR (session 3) | 1832 | 93.921 | 6.189 | 81.000 | 119.000 | 4.05 | 0.090 |

Outlier

| Variable | Row | Outlier |
|---|---|---|
| Sub 3 HR (session 1) | 1365 | 138 |

## 5. Fifth Site Measurements:

### Outlier Test: Subject 1 HR Session 1, Subject 1 HR Session 2, Subject 1 HR Session 3, Subject

Method

| | |
|---|---|
| Null hypothesis | All data values come from the same normal population |
| Alternative hypothesis | Smallest or largest data value is an outlier |
| Significance level | α = 0.05 |

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Subject 1 HR Session 1 | 3155 | 88.893 | 12.217 | 60.000 | 132.000 | 3.53 | 1.000 |
| Subject 1 HR Session 2 | 865 | 104.12 | 11.13 | 73.00 | 131.00 | 2.80 | 1.000 |
| Subject 1 HR Session 3 | 8314 | 92.839 | 13.511 | 57.000 | 141.000 | 3.56 | 1.000 |
| Subject 2 HR Session 1 | 2699 | 98.648 | 8.554 | 74.000 | 126.000 | 3.20 | 1.000 |
| Subject 2 HR Session 2 | 900 | 89.257 | 8.114 | 74.000 | 119.000 | 3.67 | 0.211 |
| Subject 2 HR Session 3 | 8254 | 94.487 | 10.765 | 65.000 | 130.000 | 3.30 | 1.000 |
| Subject 3 HR Session 1 | 2356 | 97.312 | 7.017 | 75.000 | 114.000 | 3.18 | 1.000 |
| Subject 3 HR Session 2 | 1071 | 92.509 | 11.567 | 69.000 | 121.000 | 2.46 | 1.000 |
| Subject 3 HR Session 3 | 8402 | 102.14 | 12.33 | 72.00 | 144.00 | 3.39 | 1.000 |
| Subject 4 HR Session 1 | 1806 | 93.006 | 11.703 | 70.000 | 120.000 | 2.31 | 1.000 |
| Subject 4 HR Session 2 | 900 | 83.193 | 7.180 | 73.000 | 106.000 | 3.18 | 1.000 |
| Subject 4 HR Session 3 | 8456 | 84.989 | 12.092 | 64.000 | 127.000 | 3.47 | 1.000 |
| Subject 5 HR Session 1 | 1558 | 96.662 | 6.388 | 76.000 | 115.000 | 3.23 | 1.000 |
| Subject 5 HR Session 2 | 902 | 95.116 | 6.594 | 79.000 | 118.000 | 3.47 | 0.450 |
| Subject 5 HR Session 3 | 8482 | 91.580 | 8.945 | 65.000 | 126.000 | 3.85 | 1.000 |

* NOTE * No outlier at the 5% level of significance

## 6. Sixth Site Measurements:

### Outlier Test: Subject 1 HR Session 1, Subject 1 HR Session 2, Subject 1 HR Session 3, Subject

Method

| | |
|---|---|
| Null hypothesis | All data values come from the same normal population |
| Alternative hypothesis | Smallest or largest data value is an outlier |
| Significance level | α = 0.05 |

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Subject 1 HR Session 1 | 5437 | 110.32 | 10.21 | 78.00 | 137.00 | 3.16 | 1.000 |
| Subject 1 HR Session 2 | 375 | 99.195 | 8.805 | 78.000 | 120.000 | 2.41 | 1.000 |
| Subject 1 HR Session 3 | 3133 | 104.30 | 7.41 | 77.00 | 127.00 | 3.69 | 0.706 |
| Subject 2 HR Session 1 | 4196 | 91.939 | 8.760 | 70.000 | 130.000 | 4.35 | 0.057 |
| Subject 2 HR Session 2 | 803 | 79.976 | 4.612 | 70.000 | 98.000 | 3.91 | 0.069 |
| Subject 2 HR Session 3 | 3428 | 84.428 | 8.259 | 64.000 | 117.000 | 3.94 | 0.270 |
| Subject 3 HR Session 1 | 3061 | 101.03 | 9.48 | 81.00 | 125.00 | 2.53 | 1.000 |
| Subject 3 HR Session 2 | 1085 | 90.529 | 3.275 | 81.000 | 102.000 | 3.50 | 0.482 |
| Subject 3 HR Session 3 | 4301 | 84.540 | 7.771 | 70.000 | 111.000 | 3.41 | 1.000 |
| Subject 4 HR Session 1 | 2622 | 90.238 | 6.727 | 68.000 | 115.000 | 3.68 | 0.598 |
| Subject 4 HR Session 2 | 662 | 85.414 | 5.014 | 75.000 | 102.000 | 3.31 | 0.595 |
| Subject 4 HR Session 3 | 4585 | 87.835 | 6.529 | 71.000 | 112.000 | 3.70 | 0.973 |
| Subject 3 HR Session 1 | 3061 | 101.03 | 9.48 | 81.00 | 125.00 | 2.53 | 1.000 |
| Subject 5 HR Session 2 | 1160 | 77.618 | 4.836 | 67.000 | 94.000 | 3.39 | 0.796 |
| Subject 5 HR Session 3 | 3158 | 85.058 | 14.451 | 63.000 | 134.000 | 3.39 | 1.000 |

* NOTE * No outlier at the 5% level of significance

## 7. Seventh Site Measurements:

### Outlier Test: Subject 1 HR Session 1, Subject 1 HR Session 2, Subject 1 HR Session 3, Subject

Method

| | |
|---|---|
| Null hypothesis | All data values come from the same normal population |
| Alternative hypothesis | Smallest or largest data value is an outlier |
| Significance level | α = 0.05 |

Grubbs' Test

| Variable | N | Mean | StDev | Min | Max | G | P |
|---|---|---|---|---|---|---|---|
| Subject 1 HR Session 1 | 2627 | 101.11 | 7.50 | 74.00 | 122.00 | 3.61 | 0.782 |
| Subject 1 HR Session 2 | 343 | 87.723 | 4.230 | 77.000 | 101.000 | 3.14 | 0.542 |
| Subject 1 HR Session 3 | 2443 | 91.856 | 7.268 | 74.000 | 115.000 | 3.18 | 1.000 |
| Subject 2 HR Session 1 | 1446 | 118.66 | 17.24 | 84.00 | 166.00 | 2.75 | 1.000 |
| Subject 2 HR Session 2 | 894 | 81.054 | 5.220 | 67.000 | 98.000 | 3.25 | 1.000 |
| Subject 2 HR Session 3 | 2941 | 105.11 | 11.06 | 77.00 | 133.00 | 2.54 | 1.000 |
| Subject 3 HR Session 1 | 2625 | 120.86 | 9.24 | 96.00 | 144.00 | 2.69 | 1.000 |
| Subject 3 HR Session 2 | 774 | 104.22 | 3.39 | 97.00 | 115.00 | 3.18 | 1.000 |
| Subject 3 HR Session 3 | 1619 | 108.75 | 5.88 | 91.00 | 126.00 | 3.02 | 1.000 |
| Subject 4 HR Session 1 | 2341 | 123.40 | 13.02 | 70.00 | 146.00 | 4.10 | 0.093 |
| Subject 4 HR Session 2 | 839 | 97.213 | 7.794 | 76.000 | 120.000 | 2.92 | 1.000 |
| Subject 4 HR Session 3 | 1598 | 93.220 | 9.067 | 69.000 | 119.000 | 2.84 | 1.000 |
| Subject 5 HR Session 1 | 1807 | 102.52 | 8.13 | 81.00 | 132.00 | 3.63 | 0.508 |
| Subject 5 HR Session 2 | 695 | 99.193 | 4.841 | 86.000 | 118.000 | 3.89 | 0.065 |
| Subject 5 HR Session 3 | 2109 | 111.65 | 8.81 | 92.00 | 136.00 | 2.76 | 1.000 |

* NOTE * No outlier at the 5% level of significance

**Appendix-F: Kruskal-Wallis non-parametric test of temperature and humidity impact on participants' HR and BR.**

## 1. Site measurements of 2015.

### a) Kruskal-Wallis Test: HR versus Age

Kruskal-Wallis Test on HR

| Age | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 24 | 107 | 88.09 | 290.0 | -5.35 |
| 26 | 53 | 88.05 | 303.1 | -3.20 |
| 27 | 110 | 101.69 | 587.1 | 9.05 |
| 29 | 55 | 90.74 | 374.8 | -0.88 |
| 30 | 56 | 83.65 | 180.7 | -7.40 |
| 33 | 109 | 95.96 | 458.8 | 2.78 |
| 34 | 57 | 96.51 | 482.9 | 2.75 |
| 36 | 54 | 96.73 | 513.1 | 3.67 |
| 37 | 57 | 99.63 | 546.5 | 4.90 |
| 39 | 55 | 88.01 | 282.7 | -3.94 |
| 42 | 36 | 88.47 | 286.3 | -3.05 |
| 51 | 53 | 89.96 | 327.2 | -2.42 |
| Overall | 802 | | 401.5 | |

H = 234.02  DF = 11  P = 0.000
H = 234.02  DF = 11  P = 0.000  (adjusted for ties)

### b) Kruskal-Wallis Test: BR versus Age

Kruskal-Wallis Test on BR

| Age | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 24 | 107 | 19.09 | 480.3 | 3.78 |
| 26 | 53 | 20.18 | 515.0 | 3.69 |
| 27 | 110 | 17.89 | 403.9 | 0.12 |
| 29 | 55 | 17.34 | 399.3 | -0.07 |
| 30 | 56 | 17.31 | 386.7 | -0.50 |
| 33 | 109 | 16.33 | 392.3 | -0.45 |
| 34 | 57 | 13.20 | 287.3 | -3.86 |
| 36 | 54 | 13.91 | 285.9 | -3.80 |
| 37 | 57 | 17.92 | 421.9 | 0.69 |
| 39 | 55 | 18.13 | 454.4 | 1.75 |
| 42 | 36 | 16.11 | 341.5 | -1.59 |
| 51 | 53 | 16.43 | 365.4 | -1.17 |
| Overall | 802 | | 401.5 | |

H = 59.81  DF = 11  P = 0.000
H = 59.81  DF = 11  P = 0.000  (adjusted for ties)

### c) Kruskal-Wallis Test: HR versus Height

Kruskal-Wallis Test on HR

| Height | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 59.06 | 54 | 96.73 | 513.1 | 3.67 |
| 61.81 | 53 | 89.96 | 327.2 | -2.42 |

| | | | | |
|---|---|---|---|---|
| 63.78 | 53 | 88.05 | 303.1 | -3.20 |
| 64.57 | 56 | 83.65 | 180.7 | -7.40 |
| 66.14 | 51 | 92.87 | 411.0 | 0.30 |
| 66.54 | 112 | 93.65 | 429.8 | 1.40 |
| 67.32 | 55 | 103.66 | 642.8 | 8.00 |
| 67.72 | 54 | 90.06 | 314.3 | -2.86 |
| 68.11 | 91 | 94.58 | 434.5 | 1.44 |
| 68.50 | 57 | 99.63 | 546.5 | 4.90 |
| 69.29 | 53 | 86.51 | 265.3 | -4.43 |
| 69.69 | 55 | 88.01 | 282.7 | -3.94 |
| 74.80 | 58 | 97.02 | 500.8 | 3.39 |
| Overall | 802 | | 401.5 | |

```
H = 215.15  DF = 12  P = 0.000
H = 215.15  DF = 12  P = 0.000  (adjusted for ties)
```

### d) Kruskal-Wallis Test: BR versus Height

Kruskal-Wallis Test on BR

| Height | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 59.06 | 54 | 13.91 | 285.9 | -3.80 |
| 61.81 | 53 | 16.43 | 365.4 | -1.17 |
| 63.78 | 53 | 20.18 | 515.0 | 3.69 |
| 64.57 | 56 | 17.31 | 386.7 | -0.50 |
| 66.14 | 51 | 24.87 | 580.0 | 5.69 |
| 66.54 | 112 | 16.14 | 342.3 | -2.91 |
| 67.32 | 55 | 19.82 | 508.5 | 3.55 |
| 67.72 | 54 | 17.21 | 414.0 | 0.41 |
| 68.11 | 91 | 15.16 | 316.0 | -3.74 |
| 68.50 | 57 | 17.92 | 421.9 | 0.69 |
| 69.29 | 53 | 22.07 | 547.8 | 4.76 |
| 69.69 | 55 | 18.13 | 454.4 | 1.75 |
| 74.80 | 58 | 12.58 | 227.3 | -5.95 |
| Overall | 802 | | 401.5 | |

```
H = 146.81  DF = 12  P = 0.000
H = 146.81  DF = 12  P = 0.000  (adjusted for ties)
```

### e) Kruskal-Wallis Test: HR versus Weight

Kruskal-Wallis Test on HR

| Weight | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 119.05 | 57 | 99.63 | 546.5 | 4.90 |
| 136.69 | 53 | 88.05 | 303.1 | -3.20 |
| 141.10 | 53 | 86.51 | 265.3 | -4.43 |
| 143.30 | 54 | 90.06 | 314.3 | -2.86 |
| 145.51 | 55 | 90.74 | 374.8 | -0.88 |
| 154.32 | 54 | 96.73 | 513.1 | 3.67 |
| 163.14 | 53 | 89.96 | 327.2 | -2.42 |
| 165.35 | 111 | 88.83 | 354.5 | -2.30 |
| 176.37 | 57 | 96.51 | 482.9 | 2.75 |
| 178.57 | 36 | 88.47 | 286.3 | -3.05 |
| 180.78 | 51 | 92.87 | 411.0 | 0.30 |
| 182.98 | 55 | 88.01 | 282.7 | -3.94 |
| 187.39 | 55 | 103.66 | 642.8 | 8.00 |
| 198.42 | 58 | 97.02 | 500.8 | 3.39 |
| Overall | 802 | | 401.5 | |

H = 181.98  DF = 13  P = 0.000

H = 181.98  DF = 13  P = 0.000  (adjusted for ties)

### f) Kruskal-Wallis Test: BR versus Weight

Kruskal-Wallis Test on BR

| Weight | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 119.05 | 57 | 17.92 | 421.9 | 0.69 |
| 136.69 | 53 | 20.18 | 515.0 | 3.69 |
| 141.10 | 53 | 22.07 | 547.8 | 4.76 |
| 143.30 | 54 | 17.21 | 414.0 | 0.41 |
| 145.51 | 55 | 17.34 | 399.3 | -0.07 |
| 154.32 | 54 | 13.91 | 285.9 | -3.80 |
| 163.14 | 53 | 16.43 | 365.4 | -1.17 |
| 165.35 | 111 | 16.31 | 343.4 | -2.85 |
| 176.37 | 57 | 13.20 | 287.3 | -3.86 |
| 178.57 | 36 | 16.11 | 341.5 | -1.59 |
| 180.78 | 51 | 24.87 | 580.0 | 5.69 |
| 182.98 | 55 | 18.13 | 454.4 | 1.75 |
| 187.39 | 55 | 19.82 | 508.5 | 3.55 |
| 198.42 | 58 | 12.58 | 227.3 | -5.95 |
| Overall | 802 | | 401.5 | |

H = 150.12  DF = 13  P = 0.000

H = 150.12  DF = 13  P = 0.000  (adjusted for ties)

### g) Kruskal-Wallis Test: HR versus Degree of Temperature

Kruskal-Wallis Test on HR

| Degree of Temperature | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 28.0000 | 5 | 102.81 | 478.2 | 0.74 |
| 28.0321 | 1 | 121.37 | 786.0 | 1.66 |
| 28.0385 | 3 | 107.76 | 640.3 | 1.79 |
| 28.0449 | 5 | 87.96 | 302.5 | -0.96 |
| 28.0513 | 5 | 94.83 | 438.8 | 0.36 |
| 28.0577 | 5 | 90.53 | 384.0 | -0.17 |
| 28.0641 | 5 | 90.48 | 293.2 | -1.05 |
| 28.0705 | 5 | 89.59 | 335.9 | -0.64 |
| 28.0833 | 5 | 95.68 | 406.1 | 0.04 |
| 28.0833 | 5 | 89.92 | 388.2 | -0.13 |
| 28.1667 | 5 | 88.22 | 312.3 | -0.86 |
| 28.1667 | 5 | 93.24 | 380.8 | -0.20 |
| 28.2500 | 5 | 89.51 | 361.8 | -0.38 |
| 28.2500 | 5 | 88.41 | 288.0 | -1.10 |
| 28.3333 | 5 | 90.28 | 283.6 | -1.14 |
| 28.3333 | 5 | 85.93 | 227.4 | -1.69 |
| 28.4167 | 5 | 93.68 | 352.2 | -0.48 |
| 28.4167 | 5 | 84.47 | 171.2 | -2.23 |
| 28.5000 | 5 | 92.28 | 369.2 | -0.31 |
| 28.5000 | 5 | 84.62 | 181.6 | -2.13 |
| 28.5833 | 5 | 97.33 | 423.8 | 0.22 |
| 28.5833 | 5 | 84.61 | 239.4 | -1.57 |
| 28.6667 | 5 | 87.79 | 319.0 | -0.80 |
| 28.6667 | 5 | 90.22 | 314.6 | -0.84 |
| 28.7500 | 5 | 84.82 | 195.0 | -2.00 |
| 28.7500 | 5 | 89.65 | 332.5 | -0.67 |
| 28.8333 | 5 | 84.91 | 202.0 | -1.93 |
| 28.8333 | 5 | 88.63 | 351.0 | -0.49 |
| 28.9167 | 5 | 87.70 | 238.8 | -1.58 |

| | | | | |
|---|---|---|---|---|
| 28.9167 | 5 | 90.04 | 392.0 | -0.09 |
| 29.0000 | 10 | 90.18 | 328.6 | -1.00 |
| 31.0000 | 5 | 92.37 | 365.2 | -0.35 |
| 31.0072 | 5 | 90.66 | 290.7 | -1.07 |
| 31.0145 | 5 | 90.08 | 317.6 | -0.81 |
| 31.0217 | 5 | 84.84 | 270.6 | -1.27 |
| 31.0290 | 5 | 88.84 | 344.6 | -0.55 |
| 31.0362 | 5 | 90.38 | 422.8 | 0.21 |
| 31.0435 | 5 | 88.48 | 329.2 | -0.70 |
| 31.0507 | 5 | 91.04 | 413.8 | 0.12 |
| 31.0580 | 5 | 88.00 | 326.6 | -0.73 |
| 31.0652 | 5 | 89.10 | 312.0 | -0.87 |
| 31.0725 | 5 | 88.60 | 341.3 | -0.58 |
| 31.0797 | 5 | 88.48 | 368.0 | -0.32 |
| 31.1667 | 5 | 90.29 | 409.7 | 0.08 |
| 31.3333 | 5 | 93.32 | 382.6 | -0.18 |
| 31.5000 | 5 | 93.03 | 412.0 | 0.10 |
| 31.6667 | 5 | 95.48 | 446.7 | 0.44 |
| 31.8333 | 5 | 96.68 | 509.2 | 1.04 |
| 32.0000 | 5 | 83.03 | 261.6 | -1.35 |
| 32.0000 | 5 | 97.48 | 541.0 | 1.35 |
| 32.1667 | 5 | 87.08 | 399.4 | -0.02 |
| 32.3333 | 5 | 98.00 | 584.9 | 1.78 |
| 32.5000 | 5 | 94.05 | 437.8 | 0.35 |
| 32.6667 | 3 | 96.23 | 441.3 | 0.30 |
| 32.8333 | 3 | 122.44 | 529.3 | 0.96 |
| 32.9167 | 5 | 78.25 | 311.4 | -0.87 |
| 33.0000 | 7 | 83.58 | 251.4 | -1.72 |
| 33.8333 | 5 | 92.65 | 382.9 | -0.18 |
| 34.0000 | 5 | 82.82 | 169.7 | -2.24 |
| 34.7500 | 5 | 93.36 | 399.5 | -0.02 |
| 35.0000 | 5 | 92.79 | 321.7 | -0.77 |
| 35.6667 | 5 | 91.94 | 360.2 | -0.40 |
| 36.0000 | 5 | 90.78 | 239.0 | -1.57 |
| 36.5833 | 5 | 90.16 | 417.6 | 0.16 |
| 37.0000 | 5 | 85.50 | 181.4 | -2.13 |
| 37.5000 | 5 | 92.20 | 402.4 | 0.01 |
| 38.0000 | 5 | 81.47 | 185.7 | -2.09 |
| 38.4167 | 5 | 97.30 | 463.6 | 0.60 |
| 39.0000 | 1 | 194.43 | 802.0 | 1.73 |
| 39.0000 | 5 | 77.93 | 156.4 | -2.37 |
| 39.1667 | 1 | 70.28 | 29.0 | -1.61 |
| 39.3333 | 1 | 46.46 | 1.0 | -1.73 |
| 39.3333 | 5 | 96.58 | 470.0 | 0.66 |
| 39.5000 | 2 | 92.71 | 393.5 | -0.05 |
| 39.6667 | 4 | 91.74 | 338.8 | -0.54 |
| 39.8333 | 5 | 93.00 | 373.9 | -0.27 |
| 40.0000 | 10 | 90.69 | 310.6 | -1.25 |
| 40.1667 | 5 | 91.73 | 393.3 | -0.08 |
| 40.2500 | 5 | 100.55 | 570.4 | 1.64 |
| 40.3333 | 5 | 94.78 | 488.0 | 0.84 |
| 40.5000 | 5 | 98.27 | 572.2 | 1.65 |
| 40.6667 | 5 | 98.70 | 557.6 | 1.51 |
| 40.8333 | 6 | 100.14 | 573.7 | 1.83 |
| 41.0000 | 5 | 99.32 | 608.8 | 2.01 |
| 41.0000 | 7 | 91.00 | 390.6 | -0.13 |
| 41.1667 | 5 | 103.58 | 572.0 | 1.65 |
| 41.1667 | 4 | 94.16 | 463.5 | 0.54 |
| 41.1667 | 5 | 114.83 | 694.8 | 2.84 |
| 41.3333 | 10 | 98.16 | 460.9 | 0.82 |
| 41.5000 | 5 | 100.47 | 514.0 | 1.09 |
| 41.5000 | 5 | 104.42 | 570.2 | 1.63 |
| 41.6667 | 5 | 102.56 | 535.8 | 1.30 |

| | | | | |
|---|---|---|---|---|
| 41.6667 | 5 | 102.07 | 668.5 | 2.59 |
| 41.8333 | 10 | 102.57 | 574.8 | 2.38 |
| 42.0000 | 5 | 103.99 | 586.8 | 1.79 |
| 42.0000 | 10 | 97.73 | 442.3 | 0.56 |
| 42.0833 | 5 | 103.00 | 580.4 | 1.73 |
| 42.1667 | 5 | 98.91 | 496.8 | 0.92 |
| 42.1667 | 5 | 102.85 | 580.7 | 1.74 |
| 42.2500 | 1 | 85.83 | 201.0 | -0.87 |
| 42.3333 | 13 | 105.23 | 542.2 | 2.21 |
| 42.4167 | 4 | 99.27 | 525.9 | 1.08 |
| 42.5000 | 9 | 100.14 | 556.0 | 2.01 |
| 42.5000 | 5 | 111.91 | 590.9 | 1.83 |
| 42.5833 | 4 | 96.73 | 463.3 | 0.53 |
| 42.6667 | 10 | 97.48 | 509.0 | 1.48 |
| 42.6667 | 5 | 114.14 | 568.6 | 1.62 |
| 42.7500 | 7 | 98.28 | 428.6 | 0.31 |
| 42.8333 | 19 | 96.35 | 481.8 | 1.53 |
| 42.9167 | 9 | 93.26 | 374.8 | -0.35 |
| 43.0000 | 5 | 97.06 | 459.8 | 0.56 |
| 43.0000 | 19 | 94.58 | 416.0 | 0.28 |
| 43.0833 | 9 | 93.42 | 366.5 | -0.46 |
| 43.1667 | 5 | 91.60 | 414.2 | 0.12 |
| 43.1667 | 9 | 95.32 | 403.8 | 0.03 |
| 43.2500 | 9 | 87.88 | 387.8 | -0.18 |
| 43.3333 | 14 | 95.44 | 430.1 | 0.47 |
| 43.4167 | 9 | 94.97 | 445.3 | 0.57 |
| 43.5000 | 9 | 92.98 | 446.3 | 0.58 |
| 43.5000 | 5 | 90.46 | 370.8 | -0.30 |
| 43.5833 | 9 | 95.48 | 421.4 | 0.26 |
| 43.6667 | 9 | 96.29 | 473.7 | 0.94 |
| 43.6667 | 5 | 97.42 | 400.0 | -0.01 |
| 43.7500 | 9 | 96.59 | 485.6 | 1.09 |
| 43.8333 | 14 | 95.99 | 463.4 | 1.01 |
| 43.9167 | 9 | 95.36 | 450.0 | 0.63 |
| 44.0000 | 70 | 89.33 | 284.0 | -4.44 |
| Overall | 802 | | 401.5 | |

```
H = 193.86  DF = 126  P = 0.000
H = 193.86  DF = 126  P = 0.000  (adjusted for ties)
* NOTE * One or more small samples
```

### h) Kruskal-Wallis Test: HR versus Humidity

Kruskal-Wallis Test on HR

| Humidity | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 7.0000 | 70 | 89.33 | 284.0 | -4.44 |
| 7.0586 | 7 | 94.82 | 498.9 | 1.12 |
| 7.0833 | 9 | 95.36 | 450.0 | 0.63 |
| 7.1527 | 7 | 94.73 | 476.4 | 0.86 |
| 7.1667 | 2 | 97.97 | 557.0 | 0.95 |
| 7.1974 | 5 | 95.46 | 376.3 | -0.24 |
| 7.2468 | 7 | 93.15 | 455.7 | 0.62 |
| 7.2500 | 2 | 96.63 | 517.5 | 0.71 |
| 7.3333 | 2 | 97.10 | 536.5 | 0.83 |
| 7.3410 | 7 | 95.48 | 420.4 | 0.22 |
| 7.3949 | 5 | 97.42 | 400.0 | -0.01 |
| 7.4167 | 2 | 93.53 | 425.0 | 0.14 |
| 7.4351 | 7 | 92.27 | 441.4 | 0.46 |
| 7.5000 | 2 | 94.97 | 463.5 | 0.38 |
| 7.5293 | 7 | 94.19 | 423.1 | 0.25 |
| 7.5833 | 2 | 96.67 | 523.0 | 0.74 |
| 7.5923 | 5 | 90.46 | 370.8 | -0.30 |
| 7.6234 | 7 | 92.10 | 385.0 | -0.19 |

| | | | | |
|---|---|---|---|---|
| 7.6667 | 2 | 103.75 | 638.5 | 1.45 |
| 7.7176 | 7 | 87.88 | 363.9 | -0.43 |
| 7.7500 | 4 | 92.64 | 434.8 | 0.29 |
| 7.7897 | 5 | 94.58 | 409.9 | 0.08 |
| 7.8117 | 7 | 95.27 | 368.9 | -0.37 |
| 7.8333 | 2 | 96.82 | 526.0 | 0.76 |
| 7.8580 | 3 | 79.63 | 264.3 | -1.03 |
| 7.9059 | 7 | 92.19 | 335.3 | -0.76 |
| 7.9167 | 2 | 95.26 | 475.8 | 0.45 |
| 7.9872 | 5 | 91.60 | 414.2 | 0.12 |
| 8.0000 | 14 | 95.28 | 451.1 | 0.81 |
| 8.1026 | 3 | 101.78 | 642.7 | 1.81 |
| 8.1667 | 2 | 110.16 | 732.8 | 2.02 |
| 8.1846 | 5 | 97.06 | 459.8 | 0.56 |
| 8.1939 | 7 | 93.49 | 378.2 | -0.27 |
| 8.2500 | 9 | 93.26 | 374.8 | -0.35 |
| 8.3333 | 2 | 114.25 | 757.0 | 2.17 |
| 8.3667 | 3 | 95.00 | 451.3 | 0.37 |
| 8.3821 | 5 | 98.08 | 552.6 | 1.46 |
| 8.4745 | 5 | 85.65 | 348.3 | -0.52 |
| 8.5000 | 6 | 98.96 | 590.2 | 2.00 |
| 8.5795 | 5 | 96.71 | 543.0 | 1.37 |
| 8.6667 | 5 | 103.00 | 580.4 | 1.73 |
| 8.6667 | 2 | 114.07 | 759.0 | 2.19 |
| 8.7160 | 3 | 66.85 | 89.3 | -2.34 |
| 8.7333 | 3 | 89.28 | 443.0 | 0.31 |
| 8.7500 | 2 | 101.73 | 629.5 | 1.39 |
| 8.7551 | 3 | 85.33 | 307.0 | -0.71 |
| 8.7769 | 5 | 98.45 | 588.8 | 1.81 |
| 8.8333 | 5 | 102.85 | 580.7 | 1.74 |
| 8.8333 | 2 | 102.35 | 642.0 | 1.47 |
| 8.8923 | 3 | 100.55 | 627.3 | 1.69 |
| 8.9744 | 5 | 99.90 | 556.8 | 1.50 |
| 9.0000 | 7 | 99.64 | 641.5 | 2.75 |
| 9.0000 | 2 | 104.36 | 679.5 | 1.70 |
| 9.0357 | 2 | 89.12 | 320.0 | -0.50 |
| 9.1000 | 3 | 93.20 | 485.5 | 0.63 |
| 9.1667 | 2 | 106.09 | 677.5 | 1.69 |
| 9.1833 | 5 | 105.62 | 592.7 | 1.85 |
| 9.2500 | 4 | 107.95 | 667.3 | 2.30 |
| 9.3163 | 2 | 91.11 | 367.0 | -0.21 |
| 9.3333 | 2 | 117.84 | 773.0 | 2.27 |
| 9.3333 | 2 | 105.79 | 688.5 | 1.75 |
| 9.3667 | 5 | 102.07 | 668.5 | 2.59 |
| 9.4667 | 3 | 87.48 | 420.0 | 0.14 |
| 9.5000 | 2 | 103.93 | 663.0 | 1.60 |
| 9.5000 | 2 | 101.50 | 639.5 | 1.45 |
| 9.5500 | 5 | 104.42 | 570.2 | 1.63 |
| 9.5740 | 3 | 66.79 | 124.7 | -2.07 |
| 9.5969 | 2 | 92.31 | 395.0 | -0.04 |
| 9.6667 | 2 | 94.14 | 441.8 | 0.25 |
| 9.6821 | 3 | 99.98 | 642.7 | 1.81 |
| 9.7333 | 5 | 105.44 | 563.4 | 1.57 |
| 9.7500 | 2 | 103.09 | 656.8 | 1.56 |
| 9.8333 | 3 | 88.85 | 400.0 | -0.01 |
| 9.8333 | 4 | 94.16 | 463.5 | 0.54 |
| 9.8776 | 1 | 75.99 | 51.0 | -1.51 |
| 9.9167 | 5 | 103.58 | 572.0 | 1.65 |
| 9.9167 | 5 | 91.73 | 393.3 | -0.08 |
| 9.9167 | 1 | 96.91 | 529.0 | 0.55 |
| 10.0000 | 2 | 98.77 | 485.0 | 0.51 |
| 10.0000 | 11 | 93.71 | 464.3 | 0.90 |
| 10.0833 | 5 | 93.00 | 373.9 | -0.27 |

| | | | | |
|---|---|---|---|---|
| 10.1000 | 5 | 99.32 | 608.8 | 2.01 |
| 10.1582 | 1 | 85.83 | 201.0 | -0.87 |
| 10.1667 | 4 | 91.74 | 338.8 | -0.54 |
| 10.2000 | 3 | 94.45 | 525.0 | 0.93 |
| 10.2500 | 2 | 92.71 | 393.5 | -0.05 |
| 10.2833 | 5 | 101.77 | 582.6 | 1.75 |
| 10.3333 | 1 | 46.46 | 1.0 | -1.73 |
| 10.4167 | 1 | 70.28 | 29.0 | -1.61 |
| 10.4320 | 3 | 62.85 | 113.0 | -2.16 |
| 10.4667 | 5 | 98.70 | 557.6 | 1.51 |
| 10.4718 | 3 | 98.67 | 561.3 | 1.20 |
| 10.5000 | 1 | 194.43 | 802.0 | 1.73 |
| 10.5667 | 3 | 94.21 | 476.3 | 0.56 |
| 10.6500 | 5 | 98.27 | 572.2 | 1.65 |
| 10.6667 | 2 | 86.14 | 211.0 | -1.16 |
| 10.7500 | 2 | 84.28 | 202.0 | -1.22 |
| 10.8333 | 5 | 94.78 | 488.0 | 0.84 |
| 10.9333 | 3 | 94.27 | 434.0 | 0.24 |
| 11.2615 | 3 | 101.25 | 587.7 | 1.39 |
| 11.2900 | 3 | 63.36 | 126.0 | -2.06 |
| 11.3000 | 3 | 95.50 | 430.3 | 0.22 |
| 11.3333 | 2 | 88.90 | 317.0 | -0.52 |
| 11.5000 | 2 | 87.80 | 269.0 | -0.81 |
| 11.6667 | 3 | 86.03 | 302.7 | -0.74 |
| 12.0000 | 2 | 82.50 | 124.5 | -1.69 |
| 12.0513 | 3 | 103.14 | 589.3 | 1.41 |
| 12.1480 | 3 | 63.31 | 130.2 | -2.03 |
| 12.2500 | 2 | 87.07 | 235.0 | -1.02 |
| 12.6667 | 2 | 84.35 | 160.0 | -1.48 |
| 12.8410 | 3 | 95.60 | 540.7 | 1.04 |
| 13.0000 | 2 | 91.00 | 352.0 | -0.30 |
| 13.0060 | 3 | 63.84 | 145.7 | -1.92 |
| 13.3333 | 2 | 79.68 | 89.5 | -1.91 |
| 13.6308 | 3 | 93.36 | 465.3 | 0.48 |
| 13.7500 | 2 | 96.11 | 496.5 | 0.58 |
| 13.8640 | 3 | 67.11 | 163.7 | -1.78 |
| 14.0000 | 2 | 88.38 | 300.8 | -0.62 |
| 14.4205 | 3 | 81.00 | 269.5 | -0.99 |
| 14.5000 | 2 | 82.01 | 112.5 | -1.77 |
| 14.6667 | 2 | 100.58 | 553.0 | 0.93 |
| 14.7220 | 3 | 81.73 | 205.2 | -1.47 |
| 15.2103 | 3 | 77.59 | 275.7 | -0.94 |
| 15.2500 | 5 | 80.42 | 148.2 | -2.45 |
| 15.3333 | 2 | 90.59 | 365.0 | -0.22 |
| 15.5800 | 3 | 85.23 | 207.8 | -1.45 |
| 16.0000 | 5 | 83.03 | 261.6 | -1.35 |
| 21.0000 | 2 | 99.50 | 509.5 | 0.66 |
| 21.4167 | 3 | 122.44 | 529.3 | 0.96 |
| 21.8333 | 3 | 96.23 | 441.3 | 0.30 |
| 22.2500 | 5 | 94.05 | 437.8 | 0.35 |
| 22.6667 | 5 | 98.00 | 584.9 | 1.78 |
| 23.0833 | 5 | 87.08 | 399.4 | -0.02 |
| 23.5000 | 5 | 97.48 | 541.0 | 1.35 |
| 23.9167 | 5 | 96.68 | 509.2 | 1.04 |
| 24.3333 | 5 | 95.48 | 446.7 | 0.44 |
| 24.7500 | 5 | 93.03 | 412.0 | 0.10 |
| 25.1667 | 5 | 93.32 | 382.6 | -0.18 |
| 25.5833 | 5 | 90.29 | 409.7 | 0.08 |
| 26.0000 | 65 | 88.84 | 344.4 | -2.07 |
| 27.1667 | 5 | 90.04 | 392.0 | -0.09 |
| 28.3333 | 5 | 88.63 | 351.0 | -0.49 |
| 29.5000 | 5 | 89.65 | 332.5 | -0.67 |
| 30.6667 | 5 | 90.22 | 314.6 | -0.84 |

| | | | | |
|---|---|---|---|---|
| 31.8333 | 5 | 84.61 | 239.4 | -1.57 |
| 33.0000 | 39 | 90.10 | 353.9 | -1.32 |
| 33.5833 | 5 | 87.70 | 238.8 | -1.58 |
| 34.1667 | 10 | 84.69 | 186.6 | -2.95 |
| 34.7500 | 5 | 84.82 | 195.0 | -2.00 |
| 35.3333 | 10 | 87.25 | 273.2 | -1.76 |
| 35.9167 | 5 | 97.33 | 423.8 | 0.22 |
| 36.5000 | 5 | 92.28 | 369.2 | -0.31 |
| 36.5000 | 5 | 88.41 | 288.0 | -1.10 |
| 37.0833 | 5 | 93.68 | 352.2 | -0.48 |
| 37.6667 | 5 | 90.28 | 283.6 | -1.14 |
| 37.6667 | 5 | 93.24 | 380.8 | -0.20 |
| 38.2500 | 5 | 89.51 | 361.8 | -0.38 |
| 38.8333 | 10 | 89.63 | 350.3 | -0.70 |
| 39.4167 | 5 | 95.68 | 406.1 | 0.04 |
| 40.0000 | 5 | 102.81 | 478.2 | 0.74 |
| Overall | 802 | | 401.5 | |

H = 266.06  DF = 159  P = 0.000
H = 266.06  DF = 159  P = 0.000  (adjusted for ties)
* NOTE * One or more small samples

## i) Kruskal-Wallis Test: BR versus Degree of Temperature

Kruskal-Wallis Test on BR

| Degree of Temperature | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 28.0000 | 5 | 19.780 | 451.4 | 0.48 |
| 28.0321 | 1 | 36.646 | 789.0 | 1.67 |
| 28.0385 | 3 | 23.196 | 557.3 | 1.17 |
| 28.0449 | 5 | 16.946 | 451.0 | 0.48 |
| 28.0513 | 5 | 25.042 | 577.4 | 1.70 |
| 28.0577 | 5 | 25.425 | 652.5 | 2.43 |
| 28.0641 | 5 | 22.609 | 577.2 | 1.70 |
| 28.0705 | 5 | 22.667 | 502.0 | 0.97 |
| 28.0833 | 5 | 17.807 | 433.0 | 0.30 |
| 28.0833 | 5 | 28.516 | 605.4 | 1.97 |
| 28.1667 | 5 | 17.075 | 463.2 | 0.60 |
| 28.1667 | 5 | 23.164 | 540.8 | 1.35 |
| 28.2500 | 5 | 21.852 | 553.2 | 1.47 |
| 28.2500 | 5 | 17.461 | 419.2 | 0.17 |
| 28.3333 | 5 | 18.830 | 447.0 | 0.44 |
| 28.3333 | 5 | 18.914 | 422.8 | 0.21 |
| 28.4167 | 5 | 20.734 | 514.4 | 1.09 |
| 28.4167 | 5 | 12.756 | 292.0 | -1.06 |
| 28.5000 | 5 | 26.465 | 608.0 | 2.00 |
| 28.5000 | 5 | 11.782 | 359.4 | -0.41 |
| 28.5833 | 5 | 20.398 | 547.4 | 1.41 |
| 28.5833 | 5 | 20.177 | 487.2 | 0.83 |
| 28.6667 | 5 | 21.609 | 498.2 | 0.94 |
| 28.6667 | 5 | 16.485 | 343.8 | -0.56 |
| 28.7500 | 5 | 13.988 | 317.6 | -0.81 |
| 28.7500 | 5 | 16.820 | 371.2 | -0.29 |
| 28.8333 | 5 | 15.998 | 397.6 | -0.04 |
| 28.8333 | 5 | 18.847 | 479.0 | 0.75 |
| 28.9167 | 5 | 20.540 | 549.4 | 1.43 |
| 28.9167 | 5 | 20.640 | 585.2 | 1.78 |
| 29.0000 | 10 | 18.891 | 455.8 | 0.75 |
| 31.0000 | 5 | 21.028 | 561.0 | 1.54 |
| 31.0072 | 5 | 18.255 | 463.6 | 0.60 |
| 31.0145 | 5 | 26.337 | 547.6 | 1.41 |
| 31.0217 | 5 | 25.034 | 563.0 | 1.56 |

| | | | | |
|---|---|---|---|---|
| 31.0290 | 5 | 20.461 | 460.6 | 0.57 |
| 31.0362 | 5 | 24.905 | 648.4 | 2.39 |
| 31.0435 | 5 | 20.562 | 550.6 | 1.44 |
| 31.0507 | 5 | 21.493 | 530.0 | 1.24 |
| 31.0580 | 5 | 21.091 | 570.4 | 1.64 |
| 31.0652 | 5 | 16.257 | 381.2 | -0.20 |
| 31.0725 | 5 | 20.653 | 545.2 | 1.39 |
| 31.0797 | 5 | 21.626 | 460.2 | 0.57 |
| 31.1667 | 5 | 23.352 | 573.6 | 1.67 |
| 31.3333 | 5 | 21.398 | 545.2 | 1.39 |
| 31.5000 | 5 | 22.198 | 532.2 | 1.27 |
| 31.6667 | 5 | 22.069 | 492.6 | 0.88 |
| 31.8333 | 5 | 28.945 | 593.0 | 1.85 |
| 32.0000 | 5 | 15.312 | 378.2 | -0.23 |
| 32.0000 | 5 | 18.580 | 485.8 | 0.82 |
| 32.1667 | 5 | 20.060 | 469.0 | 0.65 |
| 32.3333 | 5 | 19.182 | 405.1 | 0.03 |
| 32.5000 | 5 | 8.128 | 144.9 | -2.48 |
| 32.6667 | 3 | 10.979 | 127.3 | -2.05 |
| 32.8333 | 3 | 5.048 | 29.3 | -2.79 |
| 32.9167 | 5 | 16.742 | 361.6 | -0.39 |
| 33.0000 | 7 | 10.392 | 191.6 | -2.41 |
| 33.8333 | 5 | 19.002 | 485.4 | 0.81 |
| 34.0000 | 5 | 13.743 | 207.2 | -1.88 |
| 34.7500 | 5 | 17.591 | 414.8 | 0.13 |
| 35.0000 | 5 | 15.679 | 297.0 | -1.01 |
| 35.6667 | 5 | 12.257 | 224.4 | -1.71 |
| 36.0000 | 5 | 11.612 | 204.0 | -1.91 |
| 36.5833 | 5 | 14.911 | 326.2 | -0.73 |
| 37.0000 | 5 | 14.506 | 299.2 | -0.99 |
| 37.5000 | 5 | 13.324 | 382.8 | -0.18 |
| 38.0000 | 5 | 13.501 | 307.4 | -0.91 |
| 38.4167 | 5 | 20.790 | 503.8 | 0.99 |
| 39.0000 | 1 | 7.201 | 29.0 | -1.61 |
| 39.0000 | 5 | 15.656 | 322.8 | -0.76 |
| 39.1667 | 1 | 1.147 | 4.0 | -1.72 |
| 39.3333 | 1 | 1.165 | 5.0 | -1.71 |
| 39.3333 | 5 | 17.273 | 309.0 | -0.90 |
| 39.5000 | 2 | 13.474 | 205.5 | -1.20 |
| 39.6667 | 4 | 16.588 | 360.8 | -0.35 |
| 39.8333 | 5 | 15.990 | 381.2 | -0.20 |
| 40.0000 | 10 | 18.917 | 421.6 | 0.28 |
| 40.1667 | 5 | 17.831 | 403.8 | 0.02 |
| 40.2500 | 5 | 18.280 | 402.2 | 0.01 |
| 40.3333 | 5 | 15.462 | 337.6 | -0.62 |
| 40.5000 | 5 | 20.707 | 525.0 | 1.20 |
| 40.6667 | 5 | 17.920 | 401.4 | -0.00 |
| 40.8333 | 6 | 19.245 | 490.3 | 0.94 |
| 41.0000 | 5 | 23.887 | 654.8 | 2.45 |
| 41.0000 | 7 | 17.830 | 372.7 | -0.33 |
| 41.1667 | 5 | 18.020 | 516.6 | 1.11 |
| 41.1667 | 4 | 13.423 | 254.3 | -1.27 |
| 41.1667 | 5 | 21.681 | 553.2 | 1.47 |
| 41.3333 | 10 | 17.576 | 402.2 | 0.01 |
| 41.5000 | 5 | 15.657 | 354.6 | -0.45 |
| 41.5000 | 5 | 20.505 | 598.8 | 1.91 |
| 41.6667 | 5 | 18.297 | 367.2 | -0.33 |
| 41.6667 | 5 | 22.394 | 568.4 | 1.62 |
| 41.8333 | 10 | 20.840 | 483.2 | 1.12 |
| 42.0000 | 5 | 24.220 | 478.0 | 0.74 |
| 42.0000 | 10 | 16.641 | 326.7 | -1.03 |
| 42.0833 | 5 | 17.565 | 458.8 | 0.55 |
| 42.1667 | 5 | 17.484 | 339.4 | -0.60 |

| | | | | |
|---|---|---|---|---|
| 42.1667 | 5 | 22.616 | 562.8 | 1.56 |
| 42.2500 | 1 | 21.829 | 606.0 | 0.88 |
| 42.3333 | 13 | 19.214 | 444.5 | 0.68 |
| 42.4167 | 4 | 12.019 | 189.0 | -1.84 |
| 42.5000 | 9 | 19.465 | 439.2 | 0.49 |
| 42.5000 | 5 | 18.445 | 376.8 | -0.24 |
| 42.5833 | 4 | 13.841 | 331.8 | -0.60 |
| 42.6667 | 10 | 16.808 | 371.1 | -0.42 |
| 42.6667 | 5 | 20.537 | 483.4 | 0.79 |
| 42.7500 | 7 | 14.487 | 253.7 | -1.70 |
| 42.8333 | 19 | 18.552 | 413.8 | 0.23 |
| 42.9167 | 9 | 12.383 | 161.8 | -3.12 |
| 43.0000 | 5 | 22.516 | 544.4 | 1.38 |
| 43.0000 | 19 | 13.380 | 281.7 | -2.28 |
| 43.0833 | 9 | 11.446 | 188.2 | -2.78 |
| 43.1667 | 5 | 17.058 | 366.2 | -0.34 |
| 43.1667 | 9 | 12.177 | 268.2 | -1.74 |
| 43.2500 | 9 | 17.859 | 371.8 | -0.39 |
| 43.3333 | 14 | 17.370 | 367.4 | -0.56 |
| 43.4167 | 9 | 16.363 | 335.3 | -0.86 |
| 43.5000 | 9 | 18.000 | 364.1 | -0.49 |
| 43.5000 | 5 | 14.472 | 331.0 | -0.68 |
| 43.5833 | 9 | 13.855 | 313.8 | -1.14 |
| 43.6667 | 9 | 15.781 | 328.7 | -0.95 |
| 43.6667 | 5 | 16.394 | 286.8 | -1.11 |
| 43.7500 | 9 | 14.878 | 293.3 | -1.41 |
| 43.8333 | 14 | 16.741 | 386.1 | -0.25 |
| 43.9167 | 9 | 16.083 | 380.7 | -0.27 |
| 44.0000 | 70 | 15.559 | 331.8 | -2.64 |
| Overall | 802 | | 401.5 | |

H = 203.17  DF = 126  P = 0.000
H = 203.17  DF = 126  P = 0.000  (adjusted for ties)
* NOTE * One or more small samples

## j) Kruskal-Wallis Test: BR versus Humidity

Kruskal-Wallis Test on BR

| Humidity | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 7.0000 | 70 | 15.559 | 331.8 | -2.64 |
| 7.0586 | 7 | 18.013 | 425.7 | 0.28 |
| 7.0833 | 9 | 16.083 | 380.7 | -0.27 |
| 7.1527 | 7 | 15.056 | 325.4 | -0.87 |
| 7.1667 | 2 | 11.782 | 142.5 | -1.58 |
| 7.1974 | 5 | 16.763 | 428.1 | 0.26 |
| 7.2468 | 7 | 15.781 | 372.1 | -0.34 |
| 7.2500 | 2 | 12.852 | 181.0 | -1.35 |
| 7.3333 | 2 | 11.989 | 176.5 | -1.38 |
| 7.3410 | 7 | 17.995 | 370.9 | -0.35 |
| 7.3949 | 5 | 16.394 | 286.8 | -1.11 |
| 7.4167 | 2 | 11.388 | 114.0 | -1.76 |
| 7.4351 | 7 | 19.846 | 432.1 | 0.35 |
| 7.5000 | 2 | 11.085 | 126.0 | -1.68 |
| 7.5293 | 7 | 17.243 | 376.1 | -0.29 |
| 7.5833 | 2 | 12.655 | 192.5 | -1.28 |
| 7.5923 | 5 | 14.472 | 331.0 | -0.68 |
| 7.6234 | 7 | 17.343 | 327.7 | -0.85 |
| 7.6667 | 2 | 19.122 | 411.0 | 0.06 |
| 7.7176 | 7 | 17.859 | 347.4 | -0.62 |
| 7.7500 | 4 | 10.382 | 244.8 | -1.36 |
| 7.7897 | 5 | 18.365 | 405.4 | 0.04 |

| | | | | |
|---|---|---|---|---|
| 7.8117 | 7 | 12.177 | 253.9 | -1.69 |
| 7.8333 | 2 | 14.677 | 318.5 | -0.51 |
| 7.8580 | 3 | 13.367 | 182.0 | -1.64 |
| 7.9059 | 7 | 12.851 | 237.6 | -1.88 |
| 7.9167 | 2 | 5.987 | 15.5 | -2.36 |
| 7.9872 | 5 | 17.058 | 366.2 | -0.34 |
| 8.0000 | 14 | 14.690 | 338.6 | -1.02 |
| 8.1026 | 3 | 17.350 | 495.0 | 0.70 |
| 8.1667 | 2 | 19.810 | 437.0 | 0.22 |
| 8.1846 | 5 | 22.516 | 544.4 | 1.38 |
| 8.1939 | 7 | 15.518 | 293.2 | -1.24 |
| 8.2500 | 9 | 12.383 | 161.8 | -3.12 |
| 8.3333 | 2 | 28.653 | 671.5 | 1.65 |
| 8.3667 | 3 | 22.129 | 596.7 | 1.46 |
| 8.3821 | 5 | 25.643 | 528.6 | 1.23 |
| 8.4745 | 5 | 14.487 | 258.4 | -1.39 |
| 8.5000 | 6 | 16.764 | 354.5 | -0.50 |
| 8.5795 | 5 | 17.672 | 407.8 | 0.06 |
| 8.6667 | 5 | 17.565 | 458.8 | 0.55 |
| 8.6667 | 2 | 19.116 | 473.0 | 0.44 |
| 8.7160 | 3 | 13.867 | 229.3 | -1.29 |
| 8.7333 | 3 | 16.362 | 358.0 | -0.33 |
| 8.7500 | 2 | 14.324 | 242.0 | -0.97 |
| 8.7551 | 3 | 15.944 | 299.8 | -0.76 |
| 8.7769 | 5 | 22.333 | 586.0 | 1.79 |
| 8.8333 | 5 | 22.616 | 562.8 | 1.56 |
| 8.8333 | 2 | 11.717 | 137.5 | -1.61 |
| 8.8923 | 3 | 18.280 | 404.0 | 0.02 |
| 8.9744 | 5 | 20.685 | 475.4 | 0.72 |
| 9.0000 | 7 | 16.853 | 348.4 | -0.61 |
| 9.0000 | 2 | 18.269 | 396.0 | -0.03 |
| 9.0357 | 2 | 20.516 | 461.5 | 0.37 |
| 9.1000 | 3 | 19.891 | 390.3 | -0.08 |
| 9.1667 | 2 | 16.169 | 345.5 | -0.34 |
| 9.1833 | 5 | 20.723 | 516.8 | 1.12 |
| 9.2500 | 4 | 16.531 | 411.8 | 0.09 |
| 9.3163 | 2 | 16.931 | 378.5 | -0.14 |
| 9.3333 | 2 | 23.188 | 640.5 | 1.46 |
| 9.3333 | 2 | 15.696 | 320.5 | -0.50 |
| 9.3667 | 5 | 22.394 | 568.4 | 1.62 |
| 9.4667 | 3 | 19.214 | 408.0 | 0.05 |
| 9.5000 | 2 | 11.813 | 133.0 | -1.64 |
| 9.5000 | 2 | 14.032 | 230.0 | -1.05 |
| 9.5500 | 5 | 20.505 | 598.8 | 1.91 |
| 9.5740 | 3 | 17.830 | 370.3 | -0.23 |
| 9.5969 | 2 | 14.498 | 256.5 | -0.89 |
| 9.6667 | 2 | 8.414 | 50.0 | -2.15 |
| 9.6821 | 3 | 17.273 | 367.0 | -0.26 |
| 9.7333 | 5 | 22.149 | 566.4 | 1.60 |
| 9.7500 | 2 | 11.548 | 121.5 | -1.71 |
| 9.8333 | 3 | 18.461 | 474.0 | 0.54 |
| 9.8333 | 4 | 13.423 | 254.3 | -1.27 |
| 9.8776 | 1 | 21.101 | 580.0 | 0.77 |
| 9.9167 | 5 | 18.020 | 516.6 | 1.11 |
| 9.9167 | 5 | 17.831 | 403.8 | 0.02 |
| 9.9167 | 1 | 12.519 | 164.0 | -1.03 |
| 10.0000 | 2 | 17.553 | 399.5 | -0.01 |
| 10.0000 | 11 | 17.637 | 344.2 | -0.83 |
| 10.0833 | 5 | 15.990 | 381.2 | -0.20 |
| 10.1000 | 5 | 23.887 | 654.8 | 2.45 |
| 10.1582 | 1 | 21.829 | 606.0 | 0.88 |
| 10.1667 | 4 | 16.588 | 360.8 | -0.35 |
| 10.2000 | 3 | 24.220 | 532.7 | 0.98 |

| | | | | |
|---|---|---|---|---|
| 10.2500 | 2 | 13.474 | 205.5 | -1.20 |
| 10.2833 | 5 | 20.729 | 555.6 | 1.49 |
| 10.3333 | 1 | 1.165 | 5.0 | -1.71 |
| 10.4167 | 1 | 1.147 | 4.0 | -1.72 |
| 10.4320 | 3 | 19.505 | 445.7 | 0.33 |
| 10.4667 | 5 | 17.920 | 401.4 | -0.00 |
| 10.4718 | 3 | 19.782 | 383.3 | -0.14 |
| 10.5000 | 1 | 7.201 | 29.0 | -1.61 |
| 10.5667 | 3 | 20.957 | 519.0 | 0.88 |
| 10.6500 | 5 | 20.707 | 525.0 | 1.20 |
| 10.6667 | 2 | 12.304 | 222.0 | -1.10 |
| 10.7500 | 2 | 9.878 | 155.5 | -1.50 |
| 10.8333 | 5 | 15.462 | 337.6 | -0.62 |
| 10.9333 | 3 | 18.716 | 398.3 | -0.02 |
| 11.2615 | 3 | 13.324 | 343.0 | -0.44 |
| 11.2900 | 3 | 20.568 | 434.3 | 0.25 |
| 11.3000 | 3 | 18.197 | 437.7 | 0.27 |
| 11.3333 | 2 | 48.718 | 684.5 | 1.73 |
| 11.5000 | 2 | 10.940 | 100.0 | -1.84 |
| 11.6667 | 3 | 17.141 | 363.3 | -0.29 |
| 12.0000 | 2 | 44.766 | 442.5 | 0.25 |
| 12.0513 | 3 | 14.911 | 266.7 | -1.01 |
| 12.1480 | 3 | 19.645 | 445.7 | 0.33 |
| 12.2500 | 2 | 11.124 | 104.5 | -1.82 |
| 12.6667 | 2 | 28.930 | 415.5 | 0.09 |
| 12.8410 | 3 | 15.045 | 305.3 | -0.72 |
| 13.0000 | 2 | 7.422 | 30.5 | -2.27 |
| 13.0060 | 3 | 18.088 | 429.0 | 0.21 |
| 13.3333 | 2 | 10.860 | 103.0 | -1.82 |
| 13.6308 | 3 | 25.350 | 616.7 | 1.61 |
| 13.7500 | 2 | 14.069 | 231.0 | -1.04 |
| 13.8640 | 3 | 16.523 | 319.7 | -0.61 |
| 14.0000 | 2 | 11.022 | 112.0 | -1.77 |
| 14.4205 | 3 | 22.858 | 552.0 | 1.13 |
| 14.5000 | 2 | 11.667 | 126.0 | -1.68 |
| 14.6667 | 2 | 17.000 | 385.5 | -0.10 |
| 14.7220 | 3 | 16.334 | 341.0 | -0.45 |
| 15.2103 | 3 | 18.274 | 475.3 | 0.55 |
| 15.2500 | 5 | 11.887 | 264.6 | -1.33 |
| 15.3333 | 2 | 11.588 | 191.0 | -1.29 |
| 15.5800 | 3 | 14.454 | 261.3 | -1.05 |
| 16.0000 | 5 | 15.312 | 378.2 | -0.23 |
| 21.0000 | 2 | 3.090 | 9.0 | -2.40 |
| 21.4167 | 3 | 5.048 | 29.3 | -2.79 |
| 21.8333 | 3 | 10.979 | 127.3 | -2.05 |
| 22.2500 | 5 | 8.128 | 144.9 | -2.48 |
| 22.6667 | 5 | 19.182 | 405.1 | 0.03 |
| 23.0833 | 5 | 20.060 | 469.0 | 0.65 |
| 23.5000 | 5 | 18.580 | 485.8 | 0.82 |
| 23.9167 | 5 | 28.945 | 593.0 | 1.85 |
| 24.3333 | 5 | 22.069 | 492.6 | 0.88 |
| 24.7500 | 5 | 22.198 | 532.2 | 1.27 |
| 25.1667 | 5 | 21.398 | 545.2 | 1.39 |
| 25.5833 | 5 | 23.352 | 573.6 | 1.67 |
| 26.0000 | 65 | 20.879 | 527.6 | 4.58 |
| 27.1667 | 5 | 20.640 | 585.2 | 1.78 |
| 28.3333 | 5 | 18.847 | 479.0 | 0.75 |
| 29.5000 | 5 | 16.820 | 371.2 | -0.29 |
| 30.6667 | 5 | 16.485 | 343.8 | -0.56 |
| 31.8333 | 5 | 20.177 | 487.2 | 0.83 |
| 33.0000 | 39 | 22.667 | 506.0 | 2.89 |
| 33.5833 | 5 | 20.540 | 549.4 | 1.43 |
| 34.1667 | 10 | 15.888 | 344.8 | -0.78 |

```
34.7500     5  13.988     317.6  -0.81
35.3333    10  20.261     460.5   0.81
35.9167     5  20.398     547.4   1.41
36.5000     5  26.465     608.0   2.00
36.5000     5  17.461     419.2   0.17
37.0833     5  20.734     514.4   1.09
37.6667     5  18.830     447.0   0.44
37.6667     5  23.164     540.8   1.35
38.2500     5  21.852     553.2   1.47
38.8333    10  20.019     534.3   1.82
39.4167     5  17.807     433.0   0.30
40.0000     5  19.780     451.4   0.48
Overall   802             401.5
H = 256.35  DF = 159  P = 0.000
H = 256.35  DF = 159  P = 0.000  (adjusted for ties)
* NOTE * One or more small samples
```

### k) Kruskal-Wallis Test: HR versus Activity

```
Kruskal-Wallis Test on HR
Activity             N  Median  Ave Rank      Z
Indoors Activity   388   91.81     363.1  -4.54
Outdoors Activity  414   94.28     437.5   4.54
Overall            802             401.5
H = 20.63  DF = 1  P = 0.000
H = 20.63  DF = 1  P = 0.000  (adjusted for ties)
```

### l) Kruskal-Wallis Test: BR versus Activity

```
Kruskal-Wallis Test on BR
Activity             N  Median  Ave Rank      Z
Indoors Activity   388   15.64     339.9  -7.30
Outdoors Activity  414   18.68     459.3   7.30
Overall            802             401.5
H = 53.23  DF = 1  P = 0.000
H = 53.23  DF = 1  P = 0.000  (adjusted for ties)
```

### m) Kruskal-Wallis Test: HR versus Activity

```
Kruskal-Wallis Test on HR
Activity                  N  Median  Ave Rank      Z
Filter preparation      197   94.19     400.8  -0.05
Formwork                182   90.58     397.2  -0.29
Resting                 191   89.67     324.3  -5.28
Shoveling                45   86.51     280.6  -3.60
Structure Installation  187   98.48     514.4   7.61
Overall                 802             401.5
H = 77.98  DF = 4  P = 0.000
H = 77.98  DF = 4  P = 0.000  (adjusted for ties)
```

### n) Kruskal-Wallis Test: BR versus Activity

```
Kruskal-Wallis Test on BR
Activity                  N  Median  Ave Rank      Z
Filter Preparation      197   14.74     300.9  -7.02
Formwork                182   18.84     465.2   4.22
Resting                 191   16.41     380.0  -1.47
```

| | | | | |
|---|---|---|---|---|
| Shoveling | 45 | 22.07 | 563.0 | 4.81 |
| Structure Installation | 187 | 18.01 | 428.5 | 1.82 |
| Overall | 802 | | 401.5 | |

H = 76.99 DF = 4 P = 0.000
H = 76.99 DF = 4 P = 0.000 (adjusted for ties)

### o) Kruskal-Wallis Test: HR versus Shift

Kruskal-Wallis Test on HR

| Shift | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| Mornning Shift | 535 | 94.52 | 422.7 | 3.67 |
| Night Shift | 267 | 90.08 | 359.1 | -3.67 |
| Overall | 802 | | 401.5 | |

H = 13.43 DF = 1 P = 0.000
H = 13.43 DF = 1 P = 0.000 (adjusted for ties)

### p) Kruskal-Wallis Test: BR versus Shift

Kruskal-Wallis Test on BR

| Shift | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| Mornning Shift | 535 | 16.45 | 363.8 | -6.52 |
| Night Shift | 267 | 19.31 | 477.0 | 6.52 |
| Overall | 802 | | 401.5 | |

H = 42.50 DF = 1 P = 0.000
H = 42.50 DF = 1 P = 0.000 (adjusted for ties)

## 2. Site measurements of 2016.

### a) Kruskal-Wallis Test: HR versus Age

Kruskal-Wallis Test on HR

| Age | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 24 | 31 | 105.75 | 415.4 | 5.41 |
| 25 | 42 | 90.72 | 206.7 | -2.71 |
| 28 | 17 | 99.82 | 359.4 | 2.44 |
| 29 | 16 | 106.78 | 401.1 | 3.46 |
| 30 | 40 | 95.65 | 243.1 | -1.10 |
| 32 | 51 | 99.58 | 272.3 | 0.16 |
| 33 | 82 | 99.79 | 313.8 | 2.84 |
| 35 | 78 | 94.85 | 240.6 | -1.75 |
| 36 | 17 | 111.97 | 465.8 | 5.31 |
| 37 | 45 | 91.84 | 222.4 | -2.10 |
| 39 | 38 | 83.48 | 132.2 | -5.64 |
| 40 | 22 | 108.12 | 439.2 | 5.25 |
| 41 | 29 | 87.97 | 137.2 | -4.70 |
| 46 | 29 | 89.46 | 195.3 | -2.63 |
| Overall | 537 | | 269.0 | |

H = 177.17 DF = 13 P = 0.000
H = 177.17 DF = 13 P = 0.000 (adjusted for ties)

### b) Kruskal-Wallis Test: HR versus Hight

Kruskal-Wallis Test on HR

| Hight | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 61.02 | 21 | 105.68 | 365.9 | 2.92 |
| 62.20 | 27 | 88.21 | 138.0 | -4.50 |

| | | | | |
|---|---|---|---|---|
| 63.78 | 38 | 83.48 | 132.2 | -5.64 |
| 65.75 | 18 | 102.50 | 349.1 | 2.23 |
| 66.14 | 40 | 95.65 | 243.1 | -1.10 |
| 66.54 | 26 | 84.32 | 210.4 | -1.97 |
| 66.93 | 111 | 103.57 | 358.0 | 6.79 |
| 67.72 | 116 | 92.90 | 229.7 | -3.08 |
| 68.50 | 25 | 100.54 | 336.7 | 2.24 |
| 69.29 | 21 | 91.75 | 177.9 | -2.75 |
| 69.69 | 33 | 107.91 | 434.4 | 6.32 |
| 74.41 | 19 | 96.26 | 262.0 | -0.20 |
| 74.80 | 42 | 90.72 | 206.7 | -2.71 |
| Overall | 537 | | 269.0 | |

H = 166.86  DF = 12  P = 0.000
H = 166.86  DF = 12  P = 0.000  (adjusted for ties)

## c) Kruskal-Wallis Test: HR versus Wight

Kruskal-Wallis Test on HR

| Wight | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 121.25 | 27 | 88.21 | 138.0 | -4.50 |
| 143.30 | 29 | 89.46 | 195.3 | -2.63 |
| 149.91 | 26 | 84.32 | 210.4 | -1.97 |
| 154.32 | 38 | 83.48 | 132.2 | -5.64 |
| 158.73 | 40 | 95.65 | 243.1 | -1.10 |
| 160.94 | 18 | 102.50 | 349.1 | 2.23 |
| 165.35 | 52 | 105.72 | 395.4 | 6.18 |
| 167.55 | 40 | 99.39 | 312.1 | 1.83 |
| 176.37 | 71 | 99.58 | 286.1 | 1.00 |
| 178.57 | 36 | 92.87 | 204.1 | -2.60 |
| 180.78 | 39 | 107.24 | 376.5 | 4.49 |
| 187.39 | 62 | 100.69 | 296.4 | 1.48 |
| 194.01 | 42 | 90.72 | 206.7 | -2.71 |
| 196.21 | 17 | 99.82 | 359.4 | 2.44 |
| Overall | 537 | | 269.0 | |

H = 142.92  DF = 13  P = 0.000
H = 142.92  DF = 13  P = 0.000  (adjusted for ties)

## d) Kruskal-Wallis Test: BR versus Age

Kruskal-Wallis Test on BR

| Age | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 24 | 31 | 22.840 | 347.4 | 2.90 |
| 25 | 42 | 20.896 | 294.4 | 1.10 |
| 28 | 17 | 16.820 | 223.5 | -1.23 |
| 29 | 16 | 24.454 | 352.9 | 2.20 |
| 30 | 40 | 15.335 | 204.9 | -2.72 |
| 32 | 51 | 18.924 | 284.9 | 0.77 |
| 33 | 82 | 18.746 | 280.7 | 0.74 |
| 35 | 78 | 18.280 | 280.2 | 0.69 |
| 36 | 17 | 21.334 | 346.4 | 2.09 |
| 37 | 45 | 17.703 | 238.0 | -1.40 |
| 39 | 38 | 13.950 | 188.2 | -3.33 |
| 40 | 22 | 9.431 | 144.9 | -3.83 |
| 41 | 29 | 17.315 | 215.2 | -1.92 |
| 46 | 29 | 23.435 | 382.8 | 4.06 |
| Overall | 537 | | 269.0 | |

H = 72.90  DF = 13  P = 0.000
H = 72.90  DF = 13  P = 0.000  (adjusted for ties)

### e) Kruskal-Wallis Test: BR versus Hight

Kruskal-Wallis Test on BR

| Hight | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 61.02 | 21 | 16.24 | 229.6 | -1.19 |
| 62.20 | 27 | 16.11 | 196.6 | -2.49 |
| 63.78 | 38 | 13.95 | 188.2 | -3.33 |
| 65.75 | 18 | 20.01 | 300.3 | 0.87 |
| 66.14 | 40 | 15.33 | 204.9 | -2.72 |
| 66.54 | 26 | 22.53 | 342.8 | 2.49 |
| 66.93 | 111 | 19.99 | 298.1 | 2.22 |
| 67.72 | 116 | 18.71 | 272.2 | 0.25 |
| 68.50 | 25 | 16.68 | 224.6 | -1.46 |
| 69.29 | 21 | 18.41 | 285.2 | 0.49 |
| 69.69 | 33 | 22.06 | 349.5 | 3.08 |
| 74.41 | 19 | 17.59 | 236.5 | -0.93 |
| 74.80 | 42 | 20.90 | 294.4 | 1.10 |
| Overall | 537 | | 269.0 | |

H = 48.06 DF = 12 P = 0.000

H = 48.06 DF = 12 P = 0.000 (adjusted for ties)

### f) Kruskal-Wallis Test: BR versus Wight

Kruskal-Wallis Test on BR

| Wight | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 121.25 | 27 | 16.11 | 196.6 | -2.49 |
| 143.30 | 29 | 23.43 | 382.8 | 4.06 |
| 149.91 | 26 | 22.53 | 342.8 | 2.49 |
| 154.32 | 38 | 13.95 | 188.2 | -3.33 |
| 158.73 | 40 | 15.33 | 204.9 | -2.72 |
| 160.94 | 18 | 20.01 | 300.3 | 0.87 |
| 165.35 | 52 | 19.60 | 299.8 | 1.51 |
| 167.55 | 40 | 17.76 | 273.9 | 0.21 |
| 176.37 | 71 | 17.39 | 249.9 | -1.11 |
| 178.57 | 36 | 20.16 | 306.8 | 1.51 |
| 180.78 | 39 | 23.00 | 338.9 | 2.92 |
| 187.39 | 62 | 16.76 | 220.5 | -2.62 |
| 194.01 | 42 | 20.90 | 294.4 | 1.10 |
| 196.21 | 17 | 16.82 | 223.5 | -1.23 |
| Overall | 537 | | 269.0 | |

H = 67.08 DF = 13 P = 0.000

H = 67.08 DF = 13 P = 0.000 (adjusted for ties)

### g) Kruskal-Wallis Test: HR versus Temperature

Kruskal-Wallis Test on HR

| Temperature | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 25.7000 | 5 | 91.00 | 205.7 | -0.92 |
| 28.4300 | 5 | 95.82 | 219.0 | -0.72 |
| 30.2400 | 5 | 91.49 | 132.6 | -1.97 |
| 30.3700 | 5 | 88.47 | 176.6 | -1.34 |
| 30.5100 | 5 | 90.37 | 217.8 | -0.74 |
| 30.7400 | 5 | 87.03 | 183.0 | -1.25 |
| 30.8800 | 5 | 92.17 | 216.2 | -0.76 |
| 31.1700 | 5 | 94.13 | 220.7 | -0.70 |
| 31.3300 | 5 | 88.68 | 155.1 | -1.65 |
| 31.3900 | 5 | 92.81 | 255.0 | -0.20 |
| 31.6200 | 5 | 87.89 | 158.4 | -1.60 |
| 31.9700 | 2 | 102.64 | 341.5 | 0.66 |
| 33.0500 | 5 | 86.68 | 132.4 | -1.98 |

| | | | | |
|---|---|---|---|---|
| 33.1700 | 5 | 89.33 | 188.6 | -1.16 |
| 33.2800 | 5 | 96.48 | 264.4 | -0.07 |
| 33.5000 | 5 | 90.44 | 216.4 | -0.76 |
| 33.6100 | 5 | 95.87 | 271.2 | 0.03 |
| 33.9100 | 5 | 102.06 | 288.6 | 0.28 |
| 33.9700 | 5 | 92.53 | 201.5 | -0.98 |
| 34.0600 | 5 | 86.23 | 178.8 | -1.31 |
| 34.1900 | 6 | 94.00 | 222.5 | -0.74 |
| 34.2800 | 5 | 92.04 | 190.1 | -1.14 |
| 34.3900 | 2 | 109.77 | 375.0 | 0.97 |
| 34.4000 | 2 | 107.23 | 398.5 | 1.18 |
| 34.4100 | 5 | 91.54 | 172.7 | -1.39 |
| 34.6500 | 4 | 91.98 | 244.8 | -0.31 |
| 34.7000 | 9 | 111.82 | 402.1 | 2.60 |
| 34.7400 | 5 | 95.64 | 258.1 | -0.16 |
| 34.8100 | 3 | 100.18 | 292.5 | 0.26 |
| 34.8600 | 5 | 100.29 | 351.4 | 1.19 |
| 34.8900 | 5 | 105.47 | 421.2 | 2.20 |
| 34.9000 | 7 | 106.85 | 364.4 | 1.64 |
| 34.9100 | 5 | 111.97 | 393.6 | 1.80 |
| 35.0100 | 5 | 94.46 | 302.2 | 0.48 |
| 35.0600 | 5 | 92.40 | 222.2 | -0.68 |
| 35.1400 | 5 | 97.67 | 264.6 | -0.06 |
| 35.1900 | 5 | 105.44 | 364.6 | 1.38 |
| 35.2000 | 10 | 107.90 | 390.4 | 2.50 |
| 35.3100 | 5 | 98.78 | 262.4 | -0.10 |
| 35.3200 | 5 | 98.74 | 354.6 | 1.24 |
| 35.3800 | 5 | 97.45 | 254.4 | -0.21 |
| 35.3900 | 10 | 104.80 | 358.7 | 1.85 |
| 35.4000 | 5 | 100.78 | 335.8 | 0.97 |
| 35.4200 | 5 | 106.31 | 384.6 | 1.67 |
| 35.4600 | 5 | 102.83 | 307.8 | 0.56 |
| 35.4836 | 3 | 108.18 | 415.3 | 1.64 |
| 35.5200 | 5 | 98.48 | 333.4 | 0.93 |
| 35.5300 | 5 | 100.14 | 342.3 | 1.06 |
| 35.6000 | 10 | 105.46 | 386.4 | 2.42 |
| 35.6500 | 5 | 89.74 | 249.5 | -0.28 |
| 35.6700 | 5 | 107.20 | 385.4 | 1.69 |
| 35.7000 | 5 | 92.26 | 232.2 | -0.53 |
| 35.7400 | 5 | 105.84 | 349.8 | 1.17 |
| 35.8100 | 5 | 103.59 | 342.0 | 1.06 |
| 35.9300 | 5 | 97.69 | 280.1 | 0.16 |
| 35.9500 | 5 | 101.89 | 351.8 | 1.20 |
| 36.0000 | 15 | 96.01 | 290.5 | 0.54 |
| 36.0700 | 5 | 88.34 | 195.8 | -1.06 |
| 36.0900 | 5 | 121.17 | 449.9 | 2.62 |
| 36.2300 | 5 | 87.24 | 147.8 | -1.75 |
| 36.2600 | 3 | 97.79 | 227.0 | -0.47 |
| 36.2800 | 5 | 89.46 | 231.8 | -0.54 |
| 36.3000 | 5 | 105.57 | 345.8 | 1.11 |
| 36.3300 | 1 | 100.53 | 331.0 | 0.40 |
| 36.4000 | 5 | 86.84 | 170.1 | -1.43 |
| 36.4300 | 5 | 89.15 | 195.4 | -1.07 |
| 36.4600 | 5 | 87.91 | 151.6 | -1.70 |
| 36.4800 | 1 | 84.60 | 77.0 | -1.24 |
| 36.4900 | 5 | 92.33 | 151.0 | -1.71 |
| 36.6000 | 15 | 98.62 | 266.6 | -0.06 |
| 36.8000 | 5 | 91.82 | 190.6 | -1.14 |
| 36.8300 | 5 | 99.63 | 258.8 | -0.15 |
| 36.9900 | 5 | 83.53 | 116.0 | -2.22 |
| 37.0000 | 10 | 87.05 | 169.8 | -2.04 |
| 37.0300 | 5 | 92.71 | 221.8 | -0.68 |
| 37.1300 | 5 | 94.83 | 208.8 | -0.87 |

| | | | | |
|---|---|---|---|---|
| 37.3000 | 15 | 82.75 | 137.6 | -3.33 |
| 37.3200 | 5 | 93.54 | 252.9 | -0.23 |
| 37.4300 | 5 | 95.78 | 285.8 | 0.24 |
| 37.5000 | 5 | 82.35 | 128.2 | -2.04 |
| 37.5200 | 5 | 88.62 | 184.6 | -1.22 |
| 37.6000 | 5 | 96.94 | 257.2 | -0.17 |
| 37.6100 | 5 | 95.75 | 208.2 | -0.88 |
| 37.6300 | 8 | 98.13 | 260.8 | -0.15 |
| 37.7200 | 5 | 94.07 | 242.4 | -0.39 |
| 37.8500 | 5 | 100.61 | 302.4 | 0.48 |
| 37.9000 | 5 | 93.22 | 196.0 | -1.06 |
| 37.9100 | 5 | 86.85 | 136.7 | -1.92 |
| 37.9300 | 5 | 92.36 | 215.4 | -0.78 |
| 38.0100 | 5 | 103.21 | 371.8 | 1.49 |
| 38.2000 | 5 | 97.91 | 307.2 | 0.55 |
| 38.2200 | 2 | 107.68 | 433.5 | 1.50 |
| 38.2300 | 5 | 105.64 | 355.0 | 1.25 |
| 38.2500 | 1 | 120.09 | 505.0 | 1.52 |
| 38.3400 | 5 | 99.82 | 306.2 | 0.54 |
| 38.4000 | 4 | 98.30 | 269.8 | 0.01 |
| 38.4600 | 5 | 101.79 | 341.2 | 1.05 |
| 38.5800 | 5 | 102.01 | 343.6 | 1.08 |
| 38.7000 | 8 | 98.81 | 315.0 | 0.84 |
| 38.8200 | 4 | 127.32 | 485.8 | 2.80 |
| 38.9000 | 1 | 86.29 | 98.0 | -1.10 |
| 41.1000 | 3 | 116.77 | 469.0 | 2.24 |
| 41.6000 | 2 | 111.21 | 443.5 | 1.59 |
| 42.1000 | 1 | 102.62 | 367.0 | 0.63 |
| Overall | 537 | | 269.0 | |

H = 171.26  DF = 103  P = 0.000
H = 171.26  DF = 103  P = 0.000  (adjusted for ties)
* NOTE * One or more small samples

## h) Kruskal-Wallis Test: BR versus Temperature

Kruskal-Wallis Test on BR

| Temperature | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 25.7000 | 5 | 17.67 | 219.1 | -0.72 |
| 28.4300 | 5 | 18.39 | 258.0 | -0.16 |
| 30.2400 | 5 | 17.93 | 200.0 | -1.00 |
| 30.3700 | 5 | 14.06 | 184.4 | -1.22 |
| 30.5100 | 5 | 17.67 | 236.8 | -0.47 |
| 30.7400 | 5 | 21.82 | 308.4 | 0.57 |
| 30.8800 | 5 | 12.72 | 156.9 | -1.62 |
| 31.1700 | 5 | 15.20 | 256.0 | -0.19 |
| 31.3300 | 5 | 11.04 | 80.4 | -2.73 |
| 31.3900 | 5 | 16.96 | 271.6 | 0.04 |
| 31.6200 | 5 | 12.68 | 142.6 | -1.83 |
| 31.9700 | 2 | 10.70 | 39.5 | -2.10 |
| 33.0500 | 5 | 15.00 | 257.2 | -0.17 |
| 33.1700 | 5 | 12.79 | 146.6 | -1.77 |
| 33.2800 | 5 | 21.95 | 267.6 | -0.02 |
| 33.5000 | 5 | 22.12 | 279.4 | 0.15 |
| 33.6100 | 5 | 17.69 | 244.4 | -0.36 |
| 33.9100 | 5 | 21.99 | 334.4 | 0.95 |
| 33.9700 | 5 | 20.17 | 281.0 | 0.17 |
| 34.0600 | 5 | 15.39 | 197.6 | -1.03 |
| 34.1900 | 6 | 17.88 | 257.5 | -0.18 |
| 34.2800 | 5 | 15.89 | 161.6 | -1.56 |
| 34.3900 | 2 | 23.96 | 312.0 | 0.39 |
| 34.4000 | 2 | 19.81 | 303.5 | 0.32 |
| 34.4100 | 5 | 15.21 | 188.6 | -1.16 |

| | | | | |
|---|---|---|---|---|
| 34.6500 | 4 | 20.28 | 309.0 | 0.52 |
| 34.7000 | 9 | 20.49 | 286.1 | 0.33 |
| 34.7400 | 5 | 20.87 | 252.3 | -0.24 |
| 34.8100 | 3 | 22.72 | 380.3 | 1.25 |
| 34.8600 | 5 | 21.45 | 350.8 | 1.18 |
| 34.8900 | 5 | 24.66 | 354.6 | 1.24 |
| 34.9000 | 7 | 19.51 | 317.0 | 0.82 |
| 34.9100 | 5 | 24.74 | 358.4 | 1.29 |
| 35.0100 | 5 | 20.28 | 367.8 | 1.43 |
| 35.0600 | 5 | 21.08 | 298.9 | 0.43 |
| 35.1400 | 5 | 17.59 | 240.4 | -0.41 |
| 35.1900 | 5 | 18.03 | 236.4 | -0.47 |
| 35.2000 | 10 | 22.71 | 373.3 | 2.14 |
| 35.3100 | 5 | 26.08 | 307.8 | 0.56 |
| 35.3200 | 5 | 25.03 | 401.0 | 1.91 |
| 35.3800 | 5 | 16.22 | 252.2 | -0.24 |
| 35.3900 | 10 | 17.11 | 239.0 | -0.62 |
| 35.4000 | 5 | 16.94 | 186.8 | -1.19 |
| 35.4200 | 5 | 17.78 | 310.6 | 0.60 |
| 35.4600 | 5 | 24.26 | 357.4 | 1.28 |
| 35.4836 | 3 | 23.42 | 411.7 | 1.60 |
| 35.5200 | 5 | 20.13 | 282.6 | 0.20 |
| 35.5300 | 5 | 23.49 | 372.2 | 1.49 |
| 35.6000 | 10 | 20.64 | 294.3 | 0.52 |
| 35.6500 | 5 | 21.19 | 346.6 | 1.12 |
| 35.6700 | 5 | 19.62 | 305.2 | 0.52 |
| 35.7000 | 5 | 15.55 | 240.3 | -0.42 |
| 35.7400 | 5 | 18.64 | 319.0 | 0.72 |
| 35.8100 | 5 | 20.83 | 288.0 | 0.28 |
| 35.9300 | 5 | 26.07 | 410.0 | 2.04 |
| 35.9500 | 5 | 20.18 | 286.2 | 0.25 |
| 36.0000 | 15 | 17.33 | 220.0 | -1.24 |
| 36.0700 | 5 | 22.84 | 328.8 | 0.87 |
| 36.0900 | 5 | 21.15 | 313.0 | 0.64 |
| 36.2300 | 5 | 22.53 | 352.2 | 1.20 |
| 36.2600 | 3 | 24.10 | 286.3 | 0.19 |
| 36.2800 | 5 | 18.82 | 312.6 | 0.63 |
| 36.3000 | 5 | 22.44 | 285.0 | 0.23 |
| 36.3300 | 1 | 17.34 | 232.0 | -0.24 |
| 36.4000 | 5 | 15.64 | 202.8 | -0.96 |
| 36.4300 | 5 | 22.11 | 315.0 | 0.67 |
| 36.4600 | 5 | 19.99 | 336.8 | 0.98 |
| 36.4800 | 1 | 13.91 | 117.0 | -0.98 |
| 36.4900 | 5 | 23.54 | 303.6 | 0.50 |
| 36.6000 | 15 | 16.83 | 241.3 | -0.70 |
| 36.8000 | 5 | 15.22 | 247.6 | -0.31 |
| 36.8300 | 5 | 15.45 | 172.6 | -1.40 |
| 36.9900 | 5 | 16.61 | 226.2 | -0.62 |
| 37.0000 | 10 | 18.15 | 267.3 | -0.03 |
| 37.0300 | 5 | 13.64 | 162.6 | -1.54 |
| 37.1300 | 5 | 14.76 | 130.4 | -2.01 |
| 37.3000 | 15 | 18.69 | 231.2 | -0.96 |
| 37.3200 | 5 | 15.50 | 258.0 | -0.16 |
| 37.4300 | 5 | 23.00 | 317.6 | 0.70 |
| 37.5000 | 5 | 18.07 | 247.0 | -0.32 |
| 37.5200 | 5 | 15.16 | 211.8 | -0.83 |
| 37.6000 | 5 | 23.88 | 309.0 | 0.58 |
| 37.6100 | 5 | 14.11 | 181.0 | -1.27 |
| 37.6300 | 8 | 16.16 | 215.5 | -0.98 |
| 37.7200 | 5 | 23.50 | 303.0 | 0.49 |
| 37.8500 | 5 | 20.17 | 281.2 | 0.18 |
| 37.9000 | 5 | 15.51 | 222.4 | -0.67 |
| 37.9100 | 5 | 14.07 | 185.8 | -1.20 |

| | | | | |
|---|---|---|---|---|
| 37.9300 | 5 | 17.11 | 227.2 | -0.61 |
| 38.0100 | 5 | 24.45 | 363.6 | 1.37 |
| 38.2000 | 5 | 26.93 | 403.6 | 1.95 |
| 38.2200 | 2 | 23.42 | 355.3 | 0.79 |
| 38.2300 | 5 | 20.96 | 284.8 | 0.23 |
| 38.2500 | 1 | 17.60 | 241.0 | -0.18 |
| 38.3400 | 5 | 18.67 | 267.0 | -0.03 |
| 38.4000 | 4 | 20.46 | 281.8 | 0.16 |
| 38.4600 | 5 | 23.18 | 358.4 | 1.29 |
| 38.5800 | 5 | 19.13 | 279.4 | 0.15 |
| 38.7000 | 8 | 18.69 | 262.4 | -0.12 |
| 38.8200 | 4 | 21.85 | 350.8 | 1.06 |
| 38.9000 | 1 | 20.41 | 319.0 | 0.32 |
| 41.1000 | 3 | 15.97 | 177.3 | -1.03 |
| 41.6000 | 2 | 16.93 | 217.0 | -0.47 |
| 42.1000 | 1 | 20.85 | 328.0 | 0.38 |
| Overall | 537 | | 269.0 | |

H = 99.82  DF = 103  P = 0.570
H = 99.82  DF = 103  P = 0.570  (adjusted for ties)
* NOTE * One or more small samples

## i) Kruskal-Wallis Test: HR versus Humidity

Kruskal-Wallis Test on HR

| Humidity | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| 23.6100 | 1 | 102.62 | 367.0 | 0.63 |
| 24.1700 | 5 | 86.84 | 170.1 | -1.43 |
| 28.2500 | 5 | 89.15 | 195.4 | -1.07 |
| 28.3300 | 2 | 111.21 | 443.5 | 1.59 |
| 31.9800 | 5 | 95.64 | 258.1 | -0.16 |
| 31.9900 | 7 | 97.69 | 258.4 | -0.18 |
| 32.0000 | 10 | 90.52 | 211.9 | -1.17 |
| 32.9900 | 18 | 94.91 | 234.7 | -0.95 |
| 33.0000 | 18 | 97.28 | 239.8 | -0.81 |
| 33.0600 | 3 | 116.77 | 469.0 | 2.24 |
| 33.0700 | 5 | 87.91 | 151.6 | -1.70 |
| 33.9900 | 15 | 107.79 | 401.0 | 3.34 |
| 34.0000 | 4 | 127.32 | 485.8 | 2.80 |
| 34.9900 | 15 | 99.13 | 300.0 | 0.79 |
| 35.0000 | 15 | 99.84 | 293.6 | 0.62 |
| 35.0700 | 5 | 99.82 | 306.2 | 0.54 |
| 35.1500 | 5 | 98.48 | 333.4 | 0.93 |
| 35.2100 | 3 | 107.60 | 424.0 | 1.74 |
| 35.9900 | 12 | 97.03 | 285.5 | 0.37 |
| 36.0000 | 25 | 92.53 | 228.9 | -1.32 |
| 36.0600 | 10 | 104.43 | 363.4 | 1.94 |
| 36.1400 | 10 | 101.26 | 303.3 | 0.71 |
| 36.2200 | 5 | 95.78 | 285.8 | 0.24 |
| 36.5000 | 5 | 94.07 | 242.4 | -0.39 |
| 37.0000 | 10 | 90.81 | 216.9 | -1.07 |
| 37.1100 | 5 | 86.85 | 136.7 | -1.92 |
| 37.1600 | 2 | 107.68 | 433.5 | 1.50 |
| 37.2300 | 5 | 92.71 | 221.8 | -0.68 |
| 37.3900 | 5 | 92.36 | 215.4 | -0.78 |
| 37.4400 | 1 | 120.09 | 505.0 | 1.52 |
| 37.5200 | 5 | 93.54 | 252.9 | -0.23 |
| 38.0000 | 30 | 94.99 | 231.2 | -1.37 |
| 38.0100 | 5 | 87.89 | 158.4 | -1.60 |
| 38.2400 | 5 | 99.63 | 258.8 | -0.15 |
| 38.5500 | 5 | 94.83 | 208.8 | -0.87 |
| 38.8000 | 5 | 92.33 | 151.0 | -1.71 |
| 39.0000 | 5 | 105.61 | 342.9 | 1.07 |

```
39.1200    10   82.22     122.6  -3.01
39.3400     5  105.55     361.0   1.33
39.4300    10   85.16     145.9  -2.53
40.0000    25   90.17     229.5  -1.30
40.0100    30   90.93     199.6  -2.52
40.1200     5   95.75     208.2  -0.88
40.1300    10   95.47     203.0  -1.36
40.1400    10   88.90     213.8  -1.14
40.2200     5  100.14     342.3   1.06
40.2900     5  102.83     307.8   0.56
40.3223     3  108.18     415.3   1.64
40.3300     5   99.79     284.1   0.22
40.4300     5   87.36     162.8  -1.54
40.4500     5   83.53     116.0  -2.22
40.4800    10   86.50     157.7  -2.29
40.5700     5  106.31     384.6   1.67
41.2200    10  102.29     352.2   1.71
41.5800     5   89.74     249.5  -0.28
41.6000     5  110.12     350.6   1.18
42.0000     5  106.23     418.6   2.17
42.2300     5   94.46     302.2   0.48
42.3700     5  104.55     354.2   1.23
42.6300     5  100.29     351.4   1.19
44.0000     7  100.21     298.1   0.50
44.2500     3  100.18     292.5   0.26
44.4000     5  104.45     375.4   1.54
44.6700     4   91.98     244.8  -0.31
46.0000     5  105.68     430.2   2.33
46.4300     5  105.44     364.6   1.38
48.0000     5  108.16     428.6   2.31
48.4600     5  105.47     421.2   2.20
49.0000     4  106.26     387.3   1.53
49.4800     5  111.82     414.0   2.10
51.0000     2  107.23     398.5   1.18
51.5100     2  109.77     375.0   0.97
51.5200     1  101.38     348.0   0.51
Overall   537             269.0
H = 155.65  DF = 72  P = 0.000
H = 155.65  DF = 72  P = 0.000  (adjusted for ties)
* NOTE * One or more small samples
```

### j) Kruskal-Wallis Test: BR versus Humidity

```
Kruskal-Wallis Test on BR
Humidity     N  Median  Ave Rank      Z
23.6100      1   20.85     328.0   0.38
24.1700      5   15.64     202.8  -0.96
28.2500      5   22.11     315.0   0.67
28.3300      2   16.93     217.0  -0.47
31.9800      5   20.87     252.3  -0.24
31.9900      7   20.36     342.7   1.27
32.0000     10   16.11     223.0  -0.95
32.9900     18   19.17     267.6  -0.04
33.0000     18   21.34     292.8   0.66
33.0600      3   15.97     177.3  -1.03
33.0700      5   19.99     336.8   0.98
33.9900     15   20.18     299.9   0.78
34.0000      4   21.85     350.8   1.06
34.9900     15   19.54     260.6  -0.21
35.0000     15   20.76     288.1   0.48
35.0700      5   18.67     267.0  -0.03
```

| | | | | |
|---|---|---|---|---|
| 35.1500 | 5 | 20.13 | 282.6 | 0.20 |
| 35.2100 | 3 | 16.94 | 186.0 | -0.93 |
| 35.9900 | 12 | 12.60 | 189.4 | -1.80 |
| 36.0000 | 25 | 20.28 | 299.4 | 1.00 |
| 36.0600 | 10 | 21.44 | 324.2 | 1.14 |
| 36.1400 | 10 | 17.49 | 261.4 | -0.16 |
| 36.2200 | 5 | 23.00 | 317.6 | 0.70 |
| 36.5000 | 5 | 23.50 | 303.0 | 0.49 |
| 37.0000 | 10 | 16.17 | 234.6 | -0.71 |
| 37.1100 | 5 | 14.07 | 185.8 | -1.20 |
| 37.1600 | 2 | 23.42 | 355.3 | 0.79 |
| 37.2300 | 5 | 13.64 | 162.6 | -1.54 |
| 37.3900 | 5 | 17.11 | 227.2 | -0.61 |
| 37.4400 | 1 | 17.60 | 241.0 | -0.18 |
| 37.5200 | 5 | 15.50 | 258.0 | -0.16 |
| 38.0000 | 30 | 17.18 | 227.4 | -1.51 |
| 38.0100 | 5 | 12.68 | 142.6 | -1.83 |
| 38.2400 | 5 | 15.45 | 172.6 | -1.40 |
| 38.5500 | 5 | 14.76 | 130.4 | -2.01 |
| 38.8000 | 5 | 23.54 | 303.6 | 0.50 |
| 39.0000 | 5 | 15.09 | 127.4 | -2.05 |
| 39.1200 | 10 | 18.54 | 253.8 | -0.31 |
| 39.3400 | 5 | 18.70 | 217.2 | -0.75 |
| 39.4300 | 10 | 17.43 | 244.0 | -0.51 |
| 40.0000 | 25 | 16.74 | 247.2 | -0.72 |
| 40.0100 | 30 | 17.09 | 221.8 | -1.71 |
| 40.1200 | 5 | 14.11 | 181.0 | -1.27 |
| 40.1300 | 10 | 20.64 | 307.9 | 0.80 |
| 40.1400 | 10 | 20.83 | 320.7 | 1.06 |
| 40.2200 | 5 | 23.49 | 372.2 | 1.49 |
| 40.2900 | 5 | 24.26 | 357.4 | 1.28 |
| 40.3223 | 3 | 23.42 | 411.7 | 1.60 |
| 40.3300 | 5 | 13.49 | 184.4 | -1.22 |
| 40.4300 | 5 | 15.37 | 233.2 | -0.52 |
| 40.4500 | 5 | 16.61 | 226.2 | -0.62 |
| 40.4800 | 10 | 20.95 | 333.8 | 1.33 |
| 40.5700 | 5 | 17.78 | 310.6 | 0.60 |
| 41.2200 | 10 | 22.22 | 360.0 | 1.87 |
| 41.5800 | 5 | 21.19 | 346.6 | 1.12 |
| 41.6000 | 5 | 22.99 | 408.3 | 2.02 |
| 42.0000 | 5 | 24.70 | 321.7 | 0.76 |
| 42.2300 | 5 | 20.28 | 367.8 | 1.43 |
| 42.3700 | 5 | 18.92 | 266.8 | -0.03 |
| 42.6300 | 5 | 21.45 | 350.8 | 1.18 |
| 44.0000 | 7 | 16.94 | 204.6 | -1.11 |
| 44.2500 | 3 | 22.72 | 380.3 | 1.25 |
| 44.4000 | 5 | 15.62 | 195.6 | -1.06 |
| 44.6700 | 4 | 20.28 | 309.0 | 0.52 |
| 46.0000 | 5 | 22.43 | 338.2 | 1.00 |
| 46.4300 | 5 | 18.03 | 236.4 | -0.47 |
| 48.0000 | 5 | 23.70 | 344.2 | 1.09 |
| 48.4600 | 5 | 24.66 | 354.6 | 1.24 |
| 49.0000 | 4 | 21.70 | 345.0 | 0.98 |
| 49.4800 | 5 | 16.15 | 239.0 | -0.43 |
| 51.0000 | 2 | 19.81 | 303.5 | 0.32 |
| 51.5100 | 2 | 23.96 | 312.0 | 0.39 |
| 51.5200 | 1 | 14.28 | 128.0 | -0.91 |
| Overall | 537 | | 269.0 | |

H = 77.92  DF = 72  P = 0.296

H = 77.92  DF = 72  P = 0.296  (adjusted for ties)

* NOTE * One or more small samples

### k) Kruskal-Wallis Test: HR versus Tasks

Kruskal-Wallis Test on HR

| Tasks | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| Carpenter | 74 | 88.95 | 167.2 | -6.08 |
| Loader Deriver | 17 | 99.82 | 359.4 | 2.44 |
| Steel fixer | 82 | 96.08 | 258.1 | -0.69 |
| Steel work activity | 324 | 99.71 | 293.5 | 4.50 |
| Tower Crane Deriver | 40 | 95.65 | 243.1 | -1.10 |
| Overall | 537 | | 269.0 | |

H = 47.20  DF = 4  P = 0.000
H = 47.20  DF = 4  P = 0.000  (adjusted for ties)

### l) Kruskal-Wallis Test: BR versus Tasks

Kruskal-Wallis Test on BR

| Tasks | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| Carpenter | 74 | 17.46 | 245.9 | -1.38 |
| Loader Deriver | 17 | 16.82 | 223.5 | -1.23 |
| Steel fixer | 82 | 19.96 | 284.4 | 0.97 |
| Steel work activity | 324 | 18.82 | 280.7 | 2.15 |
| Tower Crane Deriver | 40 | 15.33 | 204.9 | -2.72 |
| Overall | 537 | | 269.0 | |

H = 12.58  DF = 4  P = 0.014
H = 12.58  DF = 4  P = 0.014  (adjusted for ties)

### m) Kruskal-Wallis Test: HR versus Shifts

Kruskal-Wallis Test on HR

| Shifts | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| Morning | 254 | 97.06 | 273.6 | 0.64 |
| Night | 283 | 96.76 | 264.9 | -0.64 |
| Overall | 537 | | 269.0 | |

H = 0.41  DF = 1  P = 0.520
H = 0.41  DF = 1  P = 0.520  (adjusted for ties)

### n) Kruskal-Wallis Test: BR versus Shifts

Kruskal-Wallis Test on BR

| Shifts | N | Median | Ave Rank | Z |
|---|---|---|---|---|
| Morning | 254 | 18.34 | 273.7 | 0.66 |
| Night | 283 | 18.58 | 264.8 | -0.66 |
| Overall | 537 | | 269.0 | |

H = 0.44  DF = 1  P = 0.509
H = 0.44  DF = 1  P = 0.509  (adjusted for ties)